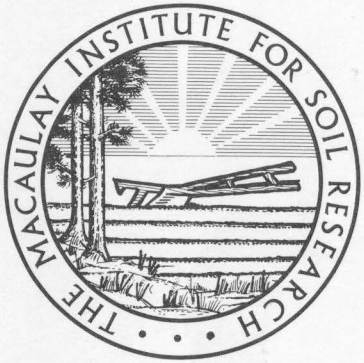
D. Jones

THE MACAULAY INSTITUTE FOR SOIL RESEARCH



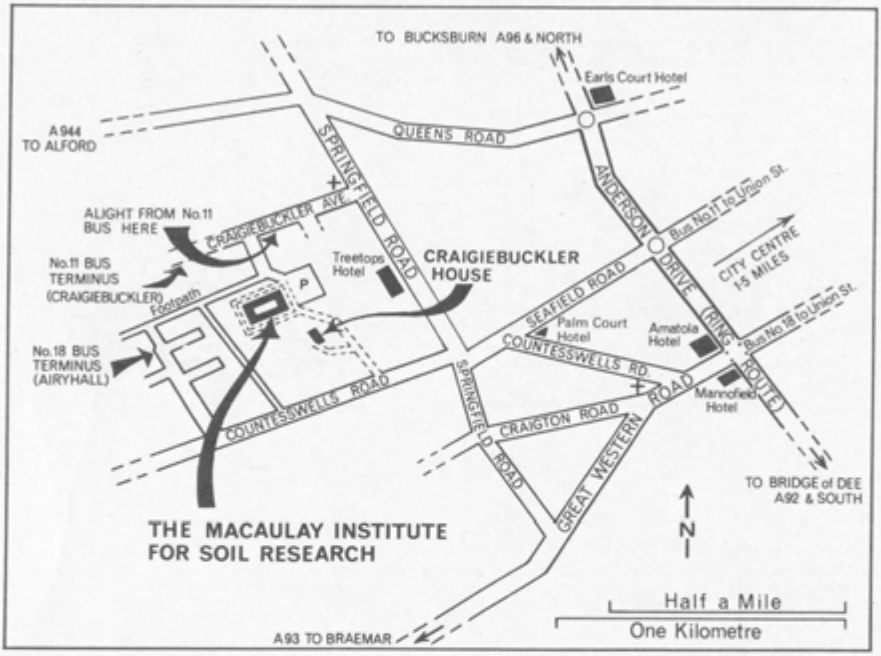
Founded 1930

1986

ANNUAL REPORT

No. 56

The Macaulay Institute for Soil Research, a company limited by guarantee, registered in Edinburgh in 1930, is one of seven Scottish state-aided agricultural research institutes which are supported by funds from the Department of Agriculture and Fisheries for Scotland and whose research programmes are co-ordinated by the Agricultural and Food Research Council.



The Macaulay Institute is situated on the western outskirts of Aberdeen, about three miles from the centre of the city. The main entrance is on Countesswells Road, but visitors using public transport should take either the Corporation Bus Route 11 to the point indicated, from which the Institute is reached in a few minutes by Craigiebuckler Drive or Bus Route 18 (less convenient) to the Airyhall terminus.

Telephone — ABERDEEN (0224) 318611
Telex — 738847 MLURI G

The main part of this report covers the period from 1st January to 31st December, 1986. The staff list is that current in December, 1986 and the Introduction is similarly updated. The report was published in May 1987.

Prior to the 12th Report (1941-42), the Annual Reports were prepared for restricted circulation only.

THE MACAULAY INSTITUTE FOR SOIL RESEARCH

CRAIGIEBUCKLER, ABERDEEN

(Founded 1930)

COUNCIL OF MANAGEMENT

Prof. H. M. Keir

Miss E. A. Piggott

Chairman —
PROFESSOR H.M. KEIR

Appointed by the Secretary of State for Scotland —
G.I. Lumsden, Esq., B.Sc., F.R.S.E.
Professor G.A. Sim, B.Sc., Ph.D.
Professor Lord Tedder, M.A., Sc.D., D.Sc., F.R.S.C., F.R.S.E.

Appointed by the University of Aberdeen —
Professor H.M. Keir, B.Sc., Ph.D., D.Sc., F.I.Biol., F.R.S.C., F.R.S.E.
Professor J.W. Parsons, B.Sc., Ph.D.
Professor C.H. Gimingham, B.A., Sc.D., Ph.D., F.I.Biol., F.R.S.E.

Appointed by the North of Scotland College of Agriculture -
W.J. Ferguson, Esq.
J.H. Topps, Esq., B.Sc., Ph.D., F.R.S.C.
G.J.F. Copeman, Esq., B.Sc.

Appointed by the West of Scotland Agricultural College -
Professor J.E. Smith, B.Sc., M.Sc., Ph.D., D.Sc., F.I.Biol., F.R.S.E.

Appointed by the East of Scotland College of Agriculture -
Professor J.C. Holmes, B.Sc., M.S., Ph.D.

Co-opted -
A.J. Grayson, Esq., M.A., M. Litt.
M. Mackie, Jnr., Esq., B.Sc., M.A.
Professor A.R. MacLeary, M.Sc., Dip.T.P., F.R.I.C.S., F.R.T.P.I., F.R.S.A.
- appointed 20.06.86

Secretary: Miss E.A. Piggott, M.B.I.M.

November 1986 Meeting of the Council of Management.
Left to Right
A.J. Grayson, G.A. Sim, J.W. Parsons, G.I. Lumsden, C.H. Gimingham, Miss E.A. Piggott, W.J. Ferguson, M. Mackie Jr., H.M. Keir, A.R. MacLeary, T.S. West, G.J.F. Copeman, J.C. Holmes, J. Topps, Lord Tedder.

STAFF

1986

Director —
PROFESSOR T.S. WEST, B.Sc., Ph.D., D.Sc., C.Chem., F.R.S.C., F.R.S.E.

MINERAL SOILS

Head of Department: M.J. Wilson, B.Sc., Ph.D., D.Sc.
W.J. McHardy, B.Sc., Ph.D.
J.M. Bracewell, B.Sc., C.Chem., F.R.S.C.
D.C. Bain, B.Sc., Ph.D.
E. Paterson, B.Sc.
A.C. Birnie, L.R.S.C., M.Sc.
B.F.L. Smith, B.Sc., M.Sc., C.Chem., M.R.S.C.
J.M. Tait, B.Sc., Ph.D.
G.W. Robertson, B.Sc.
D.M.L. Duthie, B.Sc.
R. Swaffield, L.R.S.C.
Miss C.J. Bruce
D.R. Clark
A. Mellor, B.Sc., Ph.D.
T.A.B. Walker, B.Sc. (SWAP Term Contract)
Mrs. S. Ritchie
Miss J.L. Bunch
Mrs. M.E. Reid
Miss Y. Bissett
Miss L.A. Mielewczyk
Miss M.I. Thom
Mrs. L. Forsyth
Miss S. Buchan
Miss D. McRae
Miss A. Bonner
D. Johnston

PEAT AND FOREST SOILS

Head of Department: R.A. Robertson, O.B.E., B.Sc. — retired 30.9.86
R.V. Birnie, B.Sc., Ph.D. — Acting Head
B.L. Williams, B.Sc., Ph.D.
J.D. Miller, L.R.S.C.
P.D. Hulme, B.Sc., Ph.D.
A.W. Blyth, B.Sc., L.I.Biol.
J.S. Anderson
G.G. Wright, B.Sc.
M.F. Proe, B.Sc.
Mrs. A.F. Nisbet, B.Sc., Ph.D., D.I.C. (DoE Term Contract)
T.R. Nisbet, B.Sc., Ph.D. (DoE Term Contract)
R.C. Ferrier, B.Sc., Ph.D. (SWAP Term Contract)
Mrs. J.G. Morrice, M.A.
D.R. Miller, B.Sc.
Mrs. S.M. McIntyre (née Crooke)
T. Gilmour, B.Sc. — appointed 1.2.86
Miss M.E. Young
Miss A.M. Largue — resigned 23.5.86
Mrs. K. Inglis — resigned 14.3.86
Miss J. Sutherland

Mrs P.L. Whitworth (née Horne)
Miss A.H. Finnie — appointed 2.6.86
Miss P.M. Reid — appointed 1.8.86
F.W. Milne

SPECTROCHEMISTRY

Head of Department: A.M. Ure, B.Sc., Ph.D., C. Chem., F.R.S.C. — retired 31.8.86
M.L. Berrow, B.Sc., Ph.D., C.Chem., F.R.S.C. — Acting Head
J.D. Russell, B.Sc., D.Sc., C. Chem, F.R.S.C.
J.C. Burridge, M.A., B.Sc.
B.A. Goodman, B.Sc., Ph.D.
B.L. Sharp, B.Sc., Ph.D., D.I.C., C.Chem., F.R.S.C.
M.J. Adams, G.R.S.C., Ph.D., D.I.C., C.Chem, M.R.S.C.
J.M. Ogilvie
A.R. Fraser, L.R.S.C.
J.R. Bacon, B.Sc., Ph.D.
C.A. Shand, B.Sc., Ph.D.
W. Matheson, B.Sc.
Miss I.J. Hewitt
Mrs. M.C. Mitchell
G.J. Ewen
Miss S.M. Fraser, B.Sc., Ph.D. — resigned 10.1.86.
Miss W.M. Stein
D.B. McPhail, B.Sc.
I. Black
Miss L.J.P. Potter — resigned 5.12.86.
Mrs. L.M. Keddie
I.G. Finlayson
Miss P.M. Reid — transferred to Peat & Forest Soils 1.8.86
A.J. McAllister
Mrs J.R. Noble (née Strachan)
Miss J.J. Harthill
Miss S.S. Stout
S.W. Esslemont
Miss A. Macleod — resigned 21.5.86
Miss M. Malcolm
Miss L.C. Goodwin
G.A. McPherson (SWAP Term Contract) — resigned 29.8.86
Miss M.J. McAllister — resigned 25.6.86
Mrs. A.R.B. Penman — resigned 6.5.86
Miss S. Smith
Miss A. Strathdee
Miss J. Raffan — appointed 16.6.86
G.D. Fowler (SWAP Term Contract) — appointed 3.11.86
I.M. Still
M.S. Davidson

SOIL ORGANIC CHEMISTRY

Head of Department: M.V. Cheshire, B.Sc., Ph.D. — Acting Head
I.R. MacDonald, B.Sc., Ph.D.
D. Vaughan, B.Sc., Ph.D.
H.A. Anderson, B.Sc., Ph.D.
D.J. Linehan, B.Sc., Ph.D.
C.M. Mundie, C.Chem., F.R.S.C. — retired 31.3.86
R.E. Malcolm
A. Hepburn, C.Chem., M.R.S.C.
D.C. Gordon
B.G. Ord
D.I. Welch, B.Sc., Ph.D. (SWAP Term Contract) — appointed 1.7.86
Mrs. M. Stewart
Miss R.M. Paterson
R.G. Main
Miss A.E. Thomson — resigned 5.9.86
Miss J.A. Almeida
Miss S. Campbell
Miss K.A. Wood

PLANT PHYSIOLOGY

Head of Department: A.E.S. Macklon, B.Sc., Ph.D.
A. Sim, L.R.S.C.
B. Thornton, B.Sc., Ph.D.
I.D. McFarlane
R.G. Baker, B.Sc. (HIDB Term Contract)
Mrs. M.R. Tyler

MICROBIOLOGY

Head of Department: J.F. Darbyshire, M.Sc., Ph.D., Dip.Agric.Sc.
D. Jones, M.Sc., Ph.D., M.I.Biol., F.R.M.S.
S.J. Chapman, B.Sc., Ph.D.
M.S. Davidson
R.E. Wheatley, B.Sc.
B.S. Griffiths, B.Sc., Ph.D.
S. Wood, B.Sc., Ph.D. — resigned 30.6.86
Mrs. C.E. Alexander, B.Sc., Ph.D. (EEC Term Contract)
- resigned 6.6.86
K. Ritz, B.Sc., Ph.D.
Miss K.D. Webster
Miss A.M. Smith
Miss S. Armstrong — appointed 2.6.86
Mrs. M. M. Justice

SOIL FERTILITY

Head of Department: D. Atkinson, B.Sc., Ph.D.
P.W. Dyson, B.Sc., Ph.D.
W.E. Simpson, B.Sc. — retired 30.4.86
K.S. Caldwell, S.D.A., S.D.D.H.
H. Shepherd, L.R.S.C.
A.H. Sinclair, B.Sc., Ph.D.
J.A.M. Ross, N.D.A.
G.S. Sharp, L.R.S.C.
P. Millard, B.Sc., Ph.D.
Mrs. C. Duncan
Miss L.A. Mackie, B.Sc., Ph.D.
D. Robinson, B.Sc., Ph.D.
A.C. Edwards, B.Sc., Ph.D. — appointed 24.2.86
Mrs. G. Coutts
Mrs. D.R. Donald
S.D. Porter
Mrs. E.B. Still
Mrs. E.J. Reid
C.J. Wilkinson
Mrs S. Galloway (née Main)
Miss P.J. Anderson — resigned 31.5.86
Miss C.M. Stott
Miss J.M.C. Cowe — resigned 2.5.86
A.P. Stewart
Miss L.E. Webster
Miss R.A. Downie — appointed 27.5.86
Miss S.M. Pratt — appointed 2.6.86
A.G. Gall
A.R. Douglas
J.S. Morrison — retired 31.5.86
J.A.M. Anderson
W.J. Duncan
D.W. Nelson

STATISTICS

Head of Department: R.H.E. Inkson, B.Sc., F.S.S., F.I.S.
Miss J.M. Cooper, B.Sc., Dip.Stat., M.I.S.
K.W.M. Brown, B.Sc., M.Sc., M.B.C.S. — resigned 8.8.86
G.A. Reaves, B.Sc.
Miss E.I. Duff, B.Sc.
Mrs. K.A. Hay, B.Sc.
T. Gilmour, B.Sc. — transferred to Peat & Forest Soils 1.2.86
Mrs. S.A.J. MacDonald — appointed 1.9.86
Mrs S.M. Smith (née Bissett) — resigned 31.5.86
Miss H.E.A. Brand

SOIL SURVEY

Head of Department- Professor J.S. Bibby, B.Sc.
C.J. Bown, B.Sc.
B.M. Shipley, B.Sc.
A.D. Walker, B.Sc.
D.W. Futty, B.Sc.
R.E.F. Heslop, B.Sc. (For)
J.S. Robertson, B.Sc.
F.T. Dry, B.Sc.
J.H. Gauld, B.Sc., Ph.D.
L. Robertson, B.Sc.
G. Hudson, B.Sc.
D.J. Henderson, B.Sc.
C.G.B. Campbell, B.Sc. — retired 31.12.86
W. Towers, B.Sc.
J.S. Bell, B.Sc.
J.A. Hipkin, B.Sc.
A.J. Nolan, B.Sc.
A. Lilly, B.Sc.
A.D. Moir
Miss P.R. Carnegie
Miss H.M. Paterson (Term Contract) — appointed 13.1.86
Mrs. S.J. Lilly, B.Sc. (Term Contract) — appointed 17.2.86
Mrs. L.A. Crosher (née Murray) — appointed 3.3.86
C. Halliday — retired 30.9.86

LIBRARY AND INFORMATION SERVICES

Librarian: Mrs. A.H.W. Dickie, A.L.A., M.I.Inf.Sc.
Miss M.S. Thomson

Information Officer: W.S. Shirreffs

TECHNICAL SERVICES

Head of Section: A.W. Stuart
J.H. Normington
G.J. Gaskin
A.I.A. Wilson
R.D. Malcolm
G. Sim — retired 30.6.86
J.A. Steinson — appointed 18.8.86
D.W. Clark
P. Docherty

Photographer: J. Mitchell, A.B.I.P.P., A.I.M.B.I.
D.J. Riley

ADMINISTRATION

Secretary and Treasurer:	Miss E.A. Piggott, M.B.I.M.
Personal Secretary:	Miss E.J. Cockburn
Deputy Secretary:	Mrs. M. Milne
	Mrs. C.M.R. Burness
Personal Secretary to Director:	Miss M.H.F.B. Nicol
Office Staff:	Mrs. E. Gillanders
	Miss J.M. Laing
	Miss K.E. Murdoch
	Mrs. J.S. Wales
	Mrs I.M. Shand
	Mrs. C.T. Garden
	Mrs. C.M. Smollett
	Mrs J.M. Forbes — resigned 10.1.86
	Miss L. Robertson
	Miss F.J. Cormack — appointed 27.1.86
	Miss C.A. Smith — appointed 17.2.86
Telephonist:	Mrs R.M. Simpson
Storekeeper:	A.S. Riddoch — retired 30.4.86
	Miss E.M. Middleton
Driver Handyman:	I. Findlay
Attendant:	J. Robertson
Outdoor Staff:	B.N. Kemp
	J.S. West
	C.S. Robertson
	G.A.S. Davie

HONORARY FELLOWS

E.G. Williams, B.Sc., Ph.D.
Mrs A.F. Stewart, M.A.
Miss E.J. Dey, M.B.E.
G. Anderson, B.Sc., Ph.D.

HONORARY ASSOCIATES

D.M. Webley, M.Sc., Ph.D., F.I.Biol., F.R.S.E.
R. Glentworth, B.S.A.(Manitoba), Ph.D.
R.O. Scott, B.Sc., Ph.D., A.R.C.S.T., C.Chem., F.R.S.C.
P.C. DeKock, M.Sc., D.Phil.
R.C. Mackenzie, D.Sc., Ph.D., F.G.S., F.R.S.E.
R. Grant, M.A.,B.Sc.
V.C. Farmer, B.Sc., Ph.D., C.Chem., F.R.S.C., F.R.S.E.
J.W.S. Reith, B.Sc., C.Chem., F.R.S.C.
A.M. Ure, B.Sc., Ph.D., C.Chem, F.R.S.C.
R.A. Robertson, O.B.E., B.Sc.
R.H.E. Inkson, B.Sc., F.S.S., F.I.S.

HONORARY RESEARCH ASSOCIATE

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

VISITING RESEARCH WORKERS

*Miss J.A. Armstrong, Department of Plant Physiology, (Department of Forestry, University of Aberdeen.)

*C.D. Campbell, Department of Microbiology, A.F.R.C. Research Student.

*Miss C. Flower, Department of Peat and Forest Soils, A.F.R.C. Research Student.

*J.P.J. Dicks, Department of Soil Organic Chemistry, Scotch Whisky Research Studentship.

Dr M. Doval Montoya, Department of Mineral Soils, (Universidad Complutense de Madrid, Spain.)

*R. McMahon, Department of Spectrochemistry, SWAP Studentship.

Dr P. Nadeau, Department of Mineral Soils, (Dartmouth College, Hanover, New Hampshire, U.S.A.)

Dr G. Neilsen, Department of Soil Fertility, (Agriculture Canada, Research Station, Summerland, B.C., Canada.)

Dr D. Neilsen, Department of Soil Fertility, (Agriculture Canada, Research Station, Summerland, B.C., Canada.)

Dr R. Tippkötter, Departments of Microbiology and Soil Survey, (Institut fur Bodenkunde, University of Hanover, Federal Republic of Germany.)

*G.D. Wimaladasa, Department of Soil Fertility, (Tea Research Institute, Sri Lanka.)

*Ph.D. Student.

CONTENTS

INTRODUCTION

T.S. West

The year 1986 was a traumatic one for the Institute particularly at the outset, when, in the light of the Department of Agriculture and Fisheries for Scotland's (DAFS) decision on the future budget, it was known that many staff would have to suffer redundancy by April 1987. Others would have to transfer their homes and families to Dundee and Edinburgh, there to start new careers with the Scottish Crop Research Institute (SCRI) and the Scottish Agricultural Colleges, principally at the East of Scotland College of Agriculture (ESCA). The remaining staff, possibly at a later date, might also have to transfer to Midlothian, there to amalgamate with the Hill Farming Organisation (HFRO) at the Bush Estate near Penicuik to form a new 'Macaulay' Institute concerned with land use principally in the hills and uplands of Britain.

The early months of 1986 saw a great deal of activity in relation to the location of the new institute and in identifying precisely what areas of the Institute's work would have to be diminished or reduced and the programmes that would be transferred to SCRI and ESCA. By the end of the year all these issues had been resolved, 9 staff decided to take voluntary premature retirement, 20 staff were to be transferred to SCRI along with several vacancies kept unfilled in 1985 and 1986 and 3 to the Scottish Agricultural Colleges. Sadly, 11 staff had to be issued with compulsory redundancy notices to become operative with effect from 1 April 1987. The Secretary of State for Scotland, The Right Honourable Malcolm Rifkind, having due regard to the results of a Feasibility Study, announced his decision to locate the new Macaulay Land Use Research Institute (MLURI) at Bucksburn near the Rowett Research Institute. It was further decided that the new Institute would become operative, initially from two sites, Craigiebuckler and Bush, with effect from 1 April 1987 and with its headquarters at Craigiebuckler. The present Institute will be dissolved at the same time, its Council of Management disbanded and a new governing body for MLURI, to be appointed by the Secretary of State, will become the employers of the remaining staff of MISR and the staff of HFRO.

It is undeniably sad to see the disappearance of this world-renowned institute, but the opportunities offered by the remit of a new land use research institute in conjunction with our new colleagues from the Hill Farming Research Organisation — also to be dissolved on 31 March 1987 — are manifold and attractive. In this, the last full annual report of the Macaulay Institute for Soil Research, it is both a pleasurable prospect, if somewhat tinged with regret, to look back at the achievements and

reputation established for MISR by our present and past colleagues and to look forward and wish MLURI and its staff the best of fortune and success both as a corporate body and as individuals.

In the midst of these trauma there has inevitably been some diminution in activity, but nevertheless the staff have published one hundred and five papers and have forged many collaborative links particularly, and most happily, with our new colleagues at HFRO and our neighbours at the Rowett Research Institute during 1986.

Effects of Radioactive Fall-out from the Chernobyl Nuclear Power Station Accident

The widespread distribution of radionuclides from the fusion of the Chernobyl commercial power reactor in the Soviet Union on 27 April 1986 were felt in many parts of the UK within a few days. Monitoring of rainfall, dew, milk and herbage samples began at the Institute — Section 7 — on 30 April and revealed considerably enhanced levels in many localities as shown in Table 7.21.

The most dramatic effects were seen in young lambs grazing on upland herbage. In these areas levels of radiation in grazing lambs were shown, in some instances, to be unacceptably high and limitations on the movement of animals for slaughter were introduced. The cause of these enhanced radiation levels was found to be ingestion of herbage contaminated with ^{137}Cs and ^{134}Cs from Chernobyl.

Against this background of increasing public concern and the possibility of substantial losses within the agricultural community, the Institute was invited to collaborate with the Rowett Research Institute in a project aimed at increasing the rate of excretion of radiocaesium from the contaminated animals. The work was based upon the observation that some natural minerals and synthetic compounds have the ability to sorb Cs selectively and it was thought that if these materials were incorporated into the feeds of contaminated animals then the excretion and removal of radiocaesium could be accelerated. Experiments were set up in the Department of Mineral Soils to determine (a) the most effective materials for the sorption of Cs, and (b) the stability of sorbed Cs in the acid conditions likely to be encountered in the intestines of sheep.

Four materials were tested, namely (a) synthetic potassium cobaltiferrocyanide ($K_2CoFe(CN)_6$), (b) Clinoptilolite, a natural zeolite, (c) Hydrobiotite, a vermiculite-like mineral, and (d) Bentonite, consisting largely of the mineral montmorillonite. The order of selectivity for Cs over K was established as

Ferrocyanide > Clinoptilolite > Hydrobiotite > Bentonite

The ferrocyanide effectively removes all the Cs from solution up to the 100 ppm level for a solid:liquid ratio of 1:100 whereas the minerals generally leave some 50% of the Cs in solution, even at the 10 ppm level. The results also showed that Cs associated with the ferrocyanide and

clinoptilolite was relatively stable at pH 3.0 (7% and 16% desorbed respectively) whereas that sorbed by hydrobiotite and bentonite was more easily removed (16% and 63% respectively). Experiments at the Rowett have monitored changes in whole body counts for a group of contaminated sheep treated with the above compounds and showed that the ferrocyanide complex and clinoptilolite did increase the rate of expulson of radiocaesium from the animals.

Surface Water Acidification, Acid Rain and Soil Interactions

The three year DOE acid rain study has highlighted the importance of afforestation and soil hydrology in controlling the passage of acidity into streams and lochs at Fetteresso (Aberdeenshire) and Loch Fleet (Galloway). The trees have been found to increase rainfall acidity for 11 months of the year at Loch Fleet and for 6 months at Fetteresso, reflecting the different nutrient status of the two sites. An important source of acidification resulted from NH_4^+/H^+ exchange in the tree canopy of nitrogen-deficient stands, which was shown to be reversible by the application of urea to the forest floor. Soil hydrological studies have demonstrated the predominance of the surface flow pathway, resulting from almost continually saturated soil conditions at Loch Fleet, and the steep valley slopes at Fetteresso. The surface run off at both sites was acidic and drained rapidly into the stream and loch. Afforestation had a significant effect on soil drainage.

An additional site, at Høylandet, Norway, has been instrumented as part of the SWAP project in collaboration with various Norwegian researchers. Samples from this pristine, natural site will be used in collaboration with those from the existing sites, at Loch Ard and Allt-a-Mharcaidh, to investigate mechanisms involved in leading to changes in surface water chemistry, particularly during of acidic episodes.

Forest Nutrition

Studies carried out to examine the possible mechanisms involved in the improved nutrition, particularly nitrogen, of mixed spruce compared to pure spruce stands on poor sites have been completed. Results indicate a more rapid cycling of nitrogen in mixed spruce/larch and spruce/pine and suggest that the source of the additional nitrogen is the soil, perhaps from a form which can be extracted by the nurse species and consequently becomes available to the spruce. Examination of the rainfall data has also shown that although the acidity varied at the three sites, [pHs were 3.98, 4.56 and 5.50 at Culloden (near Inverness), Inchnacardoch (near Fort Augustus) and Avondhu (S.W. Ireland)], the anions were very similar, *e.g.* sulphate — S were 1.23, 1.41 and 1.23 mgl^{-1} and nitrate — N were 0.28, 0.24 and 0.22 mgl^{-1}. It was also confirmed that the crowns of young conifer crops tend to buffer any incoming acidity.

Nutrient Cycling in Second Rotation Forest Crops

Since the inception of the Forestry Commission in 1919 the forest resource has continued to expand in the United Kingdom. Whilst planting of new

ground predominates in the private sector, a significant proportion of Forestry Commission planting now occurs on restock sites. In practice it appears that fertiliser requirements for second rotations may differ from those of the first, and research is now focussed upon the relationship between nutrient supply and demand for nutrients in restock areas through field experimentation and simulation modelling.

Nitrogen Fertilizer Responses on Poorly Drained Reseeded Blanket Peat

An experiment was set up two years ago in Sutherland to investigate poor growth of grass on reseeded blanket peat. Collaborative work between the Departments of Peat and Forest Soils and Microbiology on the peat from this site has shown that in poorly drained peat the potential for loss of fertilizer nitrate through denitrification is very high during April and May. Other processes transforming the ammonium nitrogen in peat were also active in spring and on such sites the time of application could be critical for efficient use of applied nitrogen.

Peat Survey and Remote Sensing

The first peatland map to be produced entirely by digital methods is now available for the Shetland Islands. This map has been prepared by combining the results of detailed field survey with satellite image information. The field survey identified ten peatland categories using vegetational, topographic, hydrological and land use criteria. These categories were rough drafted on a 1:50,000 base map and then vector digitised. Thereafter the entire process of map editing, text addition and preparation of the colour separations for printing was achieved using the GEMS image processing system in combination with emulation software, written to carry out the same operation on large map files, run on the PRIME mini-computer. The final, full-colour map, shows the peatland categories superimposed on a geometrically-corrected satellite image, and was printed at the National Remote Sensing Centre, RAE Farnborough, using a high resolution ink-jet printer.

The methods used in compiling the Shetland Islands peatland map have many advantages over conventional map production techniques. These include speed, ease of editing, low cost and flexibility. Although the initial process of map digitisation is time-consuming, thereafter all the editing and compilation is computer-assisted. However, the process does not simply allow the production of a map. Because the map information is stored as a series of computer files, it is possible to produce alternative one-off map products without incurring additional production costs. Another major advantage of holding the map information in digital form is that the area of each map category can be rapidly and accurately determined. By holding all map data in a standard digital format it is also possible to produce combined map products, or statistical information, drawing upon information from a number of sources. These improved ways of handling spatial data have meant that less emphasis needs to be placed on the process

of map production and greater emphasis can be placed on the use of the mapped information. This had led to the concept of a Geographic Information System.

During 1986 considerable research has been done on the application of the Geographic Information System concept, particularly to examining the extent to which the potato crop in eastern Scotland is exposed to drought-risk. This work, in collaboration with SCRI, aims to provide information which may help explain the commonly encountered shortfall between actual and predicted yields of the potato crop in eastern Scotland. The crop distribution was obtained by classification of multi-date satellite imagery. Drought-risk areas were identified through digitising of soil and potential water deficit maps. By combining these, and other spatial data sets, it was possible to show that, for one potato growing area (Kincardine & Deeside), some 9.4 per cent of the total crop was being grown in areas with a high drought-risk (1982 data). Other applications and refinements of the Geographic Information System concept are being actively pursued.

Copper Absorption by Ammonia-treated Straw

A large amount of cereal straw is produced annually and the disposal of this agricultural waste product presents considerable difficulties. As part of a collaborative research programme by the Rowett Research Institute, the North of Scotland College of Agriculture and this Institute, the use of ammoniated straw as an animal feedstuff is being intensively evaluated. Recent work in the Department of Spectrochemistry has shown that, during *in vitro* digestion with cellulase the ammoniated straw absorbs Cu more strongly than the untreated straw. Further research is planned to determine the significance of this finding for animal nutrition.

The Use of ESR Spectroscopy in Studies on Irradiated Foods

As a result of public concern about the prospect of food being sterilized by ionizing radiation, we have performed experiments to assess the potential of electron spin resonance (ESR) spectroscopy in identifying the radiation history of various materials. A number of interesting results have been obtained, the most important of which are listed below:

(i) With bone from a variety of sources we and others have shown that a stable free radical is produced in amounts proportional to the radiation dose and with an ESR spectrum that is qualitatively different from any background signal. Fig. 1 shows evidence of this effect.

(ii) Free radical production by irradiation also occurs in seeds, but in most cases the ESR signal is similar to that of melanins which occur naturally in amounts that can vary greatly, depending on factors such as ripeness. With grapes (both white and black) we have, however, observed the formation of an additional unique free radical signal.

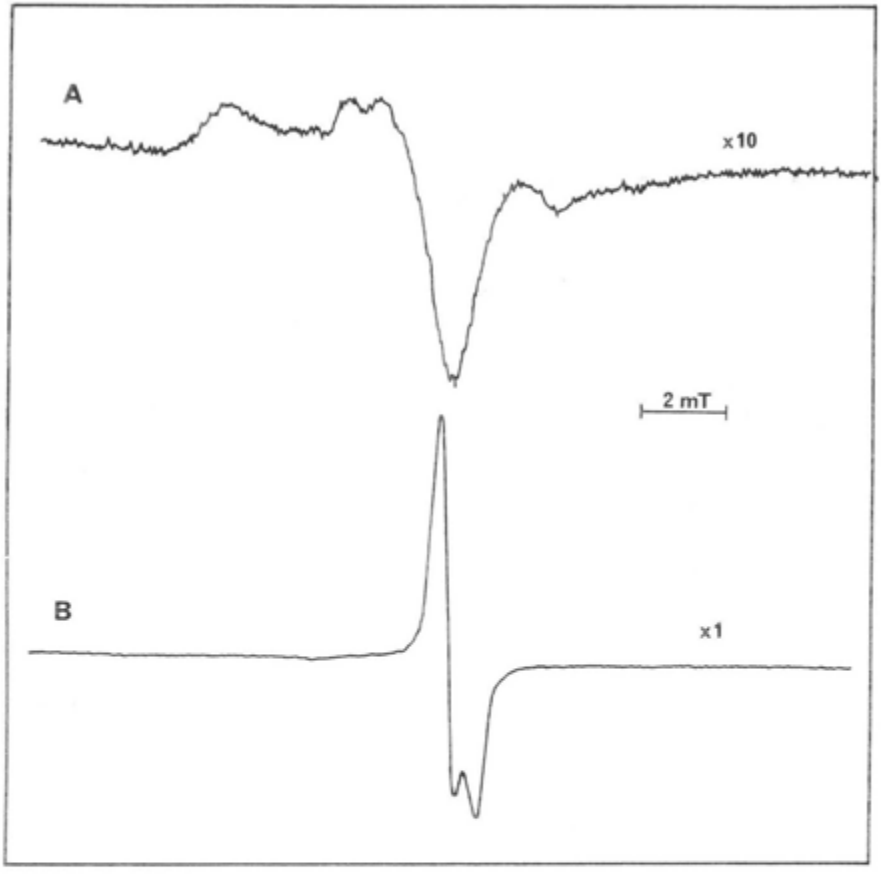


Fig 1 Electron Spin Resonance Spectra from the bone of a pork chop (a) unirradiated and (b) after approximately 5 K Gy -irradiation.

(iii) In connection with the much publicised frauds concerning prawns and related shell-fish, we have observed the production of free radicals in the shells, but not elsewhere in the material. The signal from the shell can be greatly decreased in intensity by boiling, thus severely limiting the usefulness of ESR in any procedure for detecting previous radiation treatment of such material.

Free Radicals and Heart Disease

Experiments have been carried out to investigate the validity of the theory, developed by researchers at the Rowett Research Institute, that free

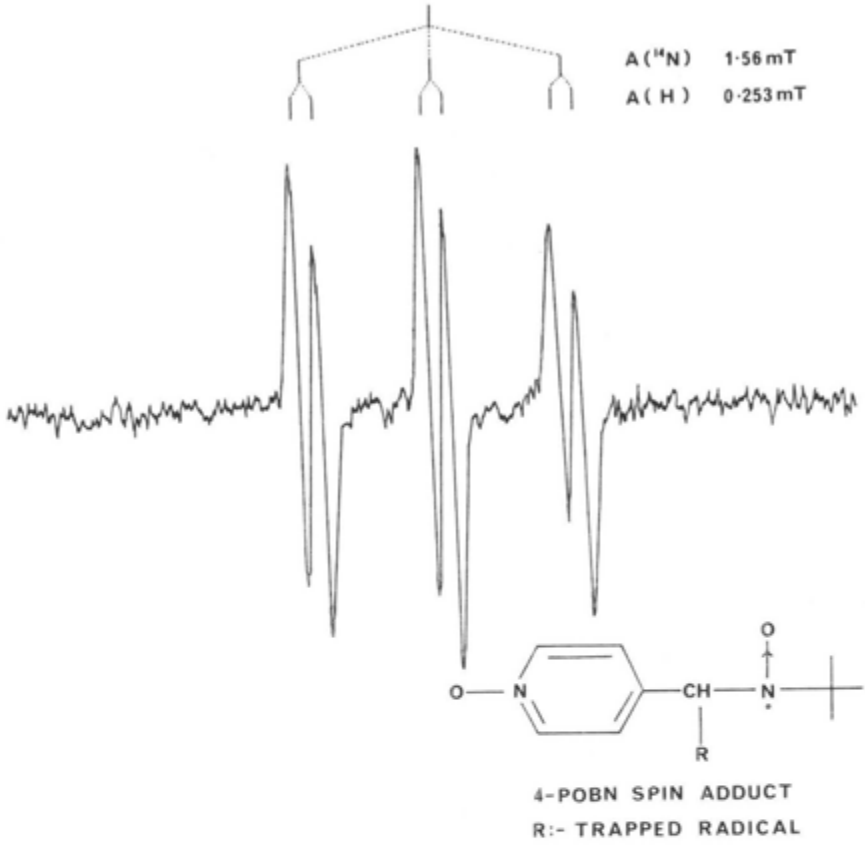


Fig 2 ESR spectrum of heart homogenate from Se and vitamin E deficient rat after incubation for 15 min. with Fe/ADP, reduced NADPH and 4-POBN (Note Fe/ADP and NADPH are used to initiate free radical production and 4-POBN is the spin trap used to scavenge short-lived free radicals produced in the tissue).
ADP adenosine 5'-diphosphate
NADPH nicotinamide dineucleotide phosphate
4-POBN α-(4-pyridyl-1-oxide)-N-tert-butyl nitrone (see Fig).

radicals have an important fundamental role in heart disease. We have developed procedures based on the use of chemical "spin traps" and electron spin resonance (ESR) spectroscopy to monitor the production of free radicals during the metabolism of 0_2 in microsomes and cell homogenates from rat liver and heart tissue. A typical spectrum is illustrated in Fig. 2, where the spectral intensity is directly related to the concentration in solution of the "trapped" radicals. These results show that dietary deficiencies of Vitamin E lead to raised levels of free radicals, this problem being exacerbated in situations of combined selenium and Vitamin E deficiency.

Uptake of Bioessential Trace Elements Co and Cu

Characterisation of the main features of *cobalt uptake* and efflux in roots of wheat seedlings has been completed. It is concluded that uptake is passive into root cell cytoplasm, where the concentration is controlled by metabolically driven active efflux of Co back to the root medium, and active accumulation into root vacuoles. Thus, the ground work has been laid for study of the factors limiting transport to the shoot, and of nutrient interactions affecting uptake.

Work on the *speciation of copper* in ryegrass leaves has made good progress. In addition to the identification of the copper protein plastocyanin, both low and high molecular weight copper complexes have been found in leaf extracts. These findings are of direct relevance to studies of copper nutrition in ruminants at the Rowett Research Institute.

Nitrogen Uptake at Cell and Whole Crop Levels

Onion roots have proved useful for characterising NO_3 fluxes in root cells, since they possess nitrate reductase activity, so that absorbed $^{15}NO_3$ is not removed from the ion transport milieu by assimilation. This has allowed estimates to be obtained of cell compartment contents, transmembrane fluxes and driving forces on nitrate ions in solutions containing NO_3 or NH_4NO_3. Characterisation of ammonium fluxes will prove more difficult due to assimilation by glutamine synthetase present in the roots.

Studies of the fate of absorbed nitrogen in the potato crop have shown that much of the nitrogen present in the tubers at harvest had been remobilized from the canopy. Much of the nitrogen in leaves is present as proteins, of which the major one is RUBISCO. Studies, with the Institute of Animal Physiology, using polyclonal antibodies have shown that RUBISCO appears to be able to function as a major storage compound. Investigations using ^{15}N labelled materials have shown that potato roots retain the capacity for nitrogen absorption late in the season when the rate of nitrogen uptake by the crop is sharply declining. Measurements of the relative efficacies with which soil-applied ammonium nitrate and foliar applied urea are used have shown higher recoveries for urea. Where potato root growth is limited by adverse soil physical conditions the volume of soil exploited is reduced and, as a consequence, nitrogen uptake; the development of the canopy and tuber production are all decreased. Also in potato, the different soil conditions produced by different cultivation implements affected the development of powdery scab as a consequence of effects on the length of time the soil remained at a high water potential.

Studies of the effect of the timing of nitrogen applications to winter wheat have shown that only in very high yielding crops does application at about the time of terminal spikelet seem to be critical. This is at variance with results from southern England. In spring barley, grown in a grass-barley rotation the application of ammonium nitrate initially raised the concentration of nitrate in the soil. This increase was rapidly reduced as a result of crop uptake and soil immobilization. Although substantial

amounts of nitrate remained in the soil in autumn none of this seemed to be derived from the current year's fertilizer application.

Nutrient Supply and Fodder Quality

Investigations, carried out jointly with the Rowett Research Institute, on the effects of feeding sulphur-deficient grass to sheep have shown that deficiency reduces protein degradation and alters the numbers of cellulytic fungi in the rumen. Applying sodium selenate immobilized on pumice granules, as a slow release formulation of selenium, was effective in raising the concentration of selenium in grass in the year of application, but seemed to have no residual effect. Measurements made, as part of the Aberdeen Straw Group's studies on the effects of ammonia-treated straw to improve its use by ruminants, on effects on the binding of Cu under conditions similar to those in the rumen have shown, as mentioned above, an increase in binding capacity with ammonia treatment.

Soil Fertility Information System

Data based on advisory analyses carried out in 1985 by the East and West Colleges of Agriculture have now been received at the Institute and have allowed the system to begin to function on an all-Scotland basis. Analysis of results is showing effects of farming system, fertilizer use and soil series on fertility levels. For elements such as potassium, soil management/fertilizer use seem to have had more effect than soil type.

Advisory Soil Analysis Methods

Substantial progress has been made towards the use of a mixed anion-cation exchange resin as a multi-element extractant for advisory analysis. Comparison with other materials of its ability to predict responses to phosphate applications has shown it to be at least as good as an anion resin and superior to acetic acid, the currently used extractant.

Studies of Plant Root Systems and Directional Growth in Roots and Stems

A major programme of studies on plant roots has been initiated. Studies in conjunction with SCRI have shown that substantial variation exists in the distribution and morphology of the spring barley root system. Methods tested during 1986 show some promise as means of evaluating root system characteristics in breeders' advanced selections. A joint study by the Departments of Soil Fertility and Mineral Soils has shown that the surfaces of field grown roots are usually covered by a tightly bound layer of soil material. This material, which seems to contain more clay and fine silt than bulk soil, is bound to the root surface by mucilage and has the potential greatly to affect root activity.

An invitation to contribute to the Tenth Long Ashton Symposium on *Hormone Action in Plant Development* provided a suitable opportunity to

present a novel theory on hormonal control of directional growth (curvature) in stems and roots. An increasing awareness of the complexities of plant growth, gained from the use of more sophisticated techniques, has revealed the inadequacy of the classical Cholodny-Went theory to account for the rapidity of opposed growth rate changes in contiguous regions, based, as that theory is, on gross trans-organ asymmetries of auxin concentration. This requirement can, however, be fully satisfied if the growth rate is controlled by auxin transport between closely adjacent tissues which are differentially sensitive to auxin. That such a situation obtains has been demonstrated with seedling hypocotyls where the epidermal tissue is stimulated by auxin and the sub-epidermal tissue is inhibited. The same mechanism can also account for the obverse curvature response of roots if, as the evidence suggests, there is a spatial transposition of auxin-positive and auxin-negative tissues between root and shoot.

Sphagnum — HIDB Contract Work

A final report on factors affecting growth and morphology of *Sphagnum* as a potential sorbent material for medical pads and wound dressings has been submitted to the Highlands and Islands Development Board. Steps to move forward to pilot plant production are now being considered by interested parties.

Significant Observations on Root Decomposition in Soil

The improved soil thin section technique, described in the 1985 Annual Report, has been used to study how roots decompose in soil. Contrary to previous expectations, some of the first signs of cell wall decomposition occur in the *inner* cortex and *not* on the outside of the root. For example, in some roots of perennial ryegrass, the central vascular tissue became detached from the outer cells of the roots and was surrounded by a large cortical void. The significance of these cortical voids as a refuge for microbial pathogens, pests, weak saprophytes and alien microorganisms introduced into the soil remains to be investigated. These results have also suggested that the rate and pattern of root decomposition varies in different agricultural plants and that root autolysis by plant enzymes may be just as important an agent of decomposition of crop residues in soil as microorganisms. The conclusions may have some impact on agronomic practice and plant breeding in the future.

Composted Tree Bark — Absorption of Silage Effluent — Medium for Mushroom Culture

Microbial studies on the composting of tree bark have continued. This year it was found that an edible fungus, *Pleurotus cornucopiae*, closely related to the Oyster mushroom, developed spontaneously without any amendments on composted bark of conifers while it was stored in a glasshouse in plastic bags (Fig. 6.4). By making small holes in the sides of

the bags, the fungus formed many fruiting bodies at these openings, apparently stimulated by light. It has also been discovered that the absorptive qualities of bark can be considerably improved by composting. For example, composted bark has been found in collaborative studies with the Department of Soil Organic Chemistry, to absorb significant quantities of silage effluents. Efforts are now being made in collaboration with the Department of Bioscience and Biotechnology at Strathclyde University to test whether composted bark saturated with silage effluent is a more effective medium for a range of edible fungi than bark on its own. If these investigations are successful, the possibility may then exist of the large scale production of valuable edible fungi and solving one of the common agricultural pollution problems at the same time.

Land Use Capability Classification for Forestry

The current debate on agricultural surpluses, alternative land uses and set aside policies, coupled with Scottish Office News Release 0349/86 giving revised criteria for forestry planting on agricultural land, has highlighted once again the need for published information on the potential of land for forestry. The News Release, based on a statement by the Rt. Hon. Malcolm Rifkind in the House of Commons, gave details of the type of land which DAFS would clear for forestry and was given in terms of agricultural land classes and soil types determined by studies at the Macaulay Institute. A classification of land capability for forestry has been developed and applied, under contract to the Nature Conservancy Council, for the Island of Islay with encouraging results. The methodology can be applied easily to the rest of Scotland and, in collaboration with the Soil Survey of England and Wales, to the remainder of UK.

Emergence of SMUDS

Arising from an initiative of the MISR/COSAC Liaison Group, much work has been done on a series of soil map unit description sheets (SMUDS). The SMUDS will be accompanied by agricultural management description sheets supplied by Colleges of Agriculture advisory staff and will be published in a convenient loose-leaf handbook. It is planned to extend the series (which now includes approximately one hundred of the most commonly occurring soil types), both in the number of map units and the management types it covers. Currently, forestry management descriptions are being designed. Publication will begin in 1987.

Domesday Project

Recognition of the Macaulay Institute as the premier source of information of the soil and vegetational characteristics of Scotland was acknowledged by the inclusion of data drawn from the National Soil Database in the recently published BBC Domesday Videodisc System. The Videodisc System provides a comprehensive view of the physical

characteristics, environment, social and economic scene in Britain in the 1980s.

Statistics and Computing

Part of the recommendations of the DAFS paper on its strategy for R and D published in December 1985 was unification of all the statisticians in the Scottish Research Institutes and the Scottish Agricultural Colleges to form a Scottish Agricultural Statistics Service (SASS)

Discussions have now been held with the Director of SASS and agreement reached on the statistical presence to be maintained within the Institute after 1 April 1987 in respect of the number of both consultant and support statisticians.

A re-assessment has been made of the Institute's central computing requirements and the system favoured is based on a Prime 2655 with 4Mb of 32-bit memory. It would provide the facilities for present needs and allow an adequate growth path to accommodate additional work arising from the remit of the Macaulay Land Use Research Institute. A decision on the proposal and a capital grant to implement it are anxiously awaited since the present central computing system has passed beyond its accepted life expectancy.

The annual census of scientific computing equipment in the Institute showed that there are now 80 mini- and micro-computers, the most numerous being "Apples". Several office word processors have also been installed throughout the Institute and it is anticipated that a FAX system will be installed in early 1987.

EVENTS AND PEOPLE

Eleventh T.B. Macaulay Lecture

The Eleventh T.B. Macaulay Lecture entitled "Achievements and Problems in Animal Production in the Hills and Uplands of Scotland" was delivered by Mr John Eadie, Director of the Hill Farming Research Organisation. This took place in the Marine Suite of the Amatola Hotel on 28 November 1986 before an audience of 200. Mr Eadie's lecture, which is presented as Appendix I to this Report, was very well received by an audience which also included staff from HFRO attending as future friends and colleagues.

Retirements

There have again been a number of retirements during the year as follows:

Mr C.M. Mundie, SSO in the Department of Soil Organic Chemistry, retired on 31 March 1986 after 40 years' service at the Institute. On leaving school in 1940, Mr Mundie came to the Institute as a lab assistant mainly employed on field work. After completing his National Service in 1946 and 1947, he returned to the Institute and worked on soil polysaccharide studies

Dynamic Duo Say Farewell.
C.M. Mundie and A.S. Riddoch.

which he continued until his retirement. He was made a Fellow of the Royal Institute of Chemistry in 1976 and during his time at the Institute served as Chairman of the Dining Room Committee and also as a committee member of IPCS. A tribute to Mr Mundie appeared in the Institute News Magazine[1].

On 30 April 1986 Mr A.S. Riddoch, Storekeeper, retired after 38 years' service. He was succeeded by his colleague Miss E.M. Middleton.

Mr W.E. Simpson, SSO in the Department of Soil Fertility, retired on 30 April, having been in charge of the advisory soil analysis laboratory for 32 years.

Mr J.S. Morrison, who worked as a fieldsman in the Department of Soil Fertility since 1970, retired on 31 May 1986.

Mr George Sim, a joiner in Technical Services, also retired on 30 June, having served the Institute for 11 years.

Dr A.M. Ure, Senior Principal Scientific Officer and Head of the Department of Spectrochemistry, retired on 31 August 1986. After graduating in Chemistry and Physics in 1945 from St Andrew's Unviersity he served as a Radar Officer with the RNVR for three years. At the end of

his service he returned to St Andrew's where he completed an Honours Degree in Chemistry in 1948. Thereafter he joined the staff of the Department of Spectrochemistry as a Scientific Officer and in 1954 was awarded the degree of PhD from Aberdeen University for a thesis entitled "The application of electronics to spectrochemistry". He was responsible for the introduction of simultaneous multi-element flame photometry as early as 1954. He has been actively concerned with the development of methods and supervised the progression from flame emission methods to atomic absorption and, more recently, inductively coupled plasma emission spectrometry. He was appointed Head of the Department in 1981. He has been closely involved with the Analytical Division of the Royal Society of Chemistry over many years and has held the office of Chairman of the Scottish Region, been a member of Council, of the Programmes and Analytical Methods Committee and of the Analytical Editorial Board. During the coming year he has the honour of delivering the 1987 Theophilus Redwood Lecture. A tribute to Dr Ure appears in Profile[2].

Mr R.A. Robertson, Senior Principal Scientific Officer and Head of the Department of Peat and Forest Soils, retired on 30 September 1986 after 35 years' service. In 1950 Mr Robertson graduated from Glasgow University with a double Honours BSc degree in Botany and Geology. On joining the Institute staff in 1951 as a Scientific Officer he worked on a heather survey as a member of the Soil Survey Section of the Department of Pedology. In 1955 he became responsible for the Peat Ecology Section, later to become Peat and Forest Soils, and in 1963 when the work of the Scottish Peat Committee was passed to the Institute Mr Robertson was then in charge of peat survey. In 1979 this section of the Division of Pedology became the Department of Peat and Forest Soils with Mr Robertson as Head of the Department. Because of the increased demand for peat survey the Department became interested in the use of aerial photography and, over the years, with the acquisition of staff and equipment the Unit of Remote Sensing was formed under Mr Robertson's guidance. From 1962 until 1968 Mr Robertson represented the UK on the International Peat Committee and on the formation of the International Peat Society, set up by the Committee in 1968, he has served as its Vice President and UK representative. To mark his efforts in the promotion of international co-operation in the fields of peat research and development he was awarded the Gold Insignia and Honorary Membership of the Technical Institute of the Polish People's Republic in 1967. In 1986 he was actively involved in launching the International Peat Society's new journal and is its first editor. Over the years he has represented the UK and served on many panels, such as the British Standards Institution, NERC Peat Survey and Hydrology Working Group, etc. He served on the Institute's IPCS Committee, becoming Chairman in 1968 and in 1980 he was Chairman of the Committee set up to organise the Institute's Jubilee celebrations. His service to agriculture and his research work on peat has this year been recognised by the award of the OBE in the Queen's Birthday Honours list. A tribute to Mr Robertson was published in the Institute's News Magazine Profile[3].

New Appointments

Dr A.C. Edwards was appointed a Higher Scientific Officer in the Department of Soil Fertility on 1 October 1986. Dr Edwards, an Honours BSc of Sunderland Polytechnic, has been working at the Institute since February 1986 on a term contract.

Mrs S.A.I. MacDonald joined the staff of the Department of Statistics as a Scientific Officer on 1 September 1986.

There have been two appointments made under the SWAP contract that was placed with the Institute by the Royal Society. These are Dr D. Welch, Higher Scientific Officer in the Department of Soil Organic Chemistry, plus an Assistant Scientific Officer in the Department of Spectrochemistry.

Resignations

Dr Sheila M. Fraser, Higher Scientific Officer in the Department of Spectrochemistry, resigned on 10 January 1986 to take up an appointment with the British Petroleum at Dyce. Dr Fraser worked at the Institute from 1983, having gained her PhD degree at Aberdeen University after carrying out her research work in the Institute from 1980 on a Ministry of Defence Scholarship.

Dr S. Wood, Higher Scientific Officer in the Department of Microbiology, resigned on 30 June 1986, having accepted a short-term contract as a research assistant at the University of Warwick. Dr Wood had worked in Microbiology for 3 years.

Mr K.W.M. Brown, Senior Scientific Officer in the Department of Statistics, resigned on 8 August 1986 having been at the Institute for 5 years. He accepted an appointment as Lecturer in Computing at the School of Mathematical Sciences and Computer Studies of Robert Gordon's Institute of Technology in Aberdeen.

Visitors to the Institute

Sir Richard Body, Chairman of the Commons Select Committee on Agriculture, visited the Institute in March. Dr J.L. Sehgal, Director of the National Bureau of Soil Science and Land Use Planning, India, visited in August, and in October a delegation from the Bureau of Geology and Mineral Resources, Hangzhou, The People's Republic of China, came to the Institute. The members of this delegation were Mr Ding Shixiang, Deputy Director, Planning and Economic Commission, Zhejiang Province, Mr Tang Wenquan, Director, Bureau of Geology and Mineral Resources, Zhejiang Province, Mr Yu Weishun, Deputy Chief Engineer, Bureau of Geology and Mineral Resources, Mr Li Guangyou, Head of Science and Technology Division, Bureau of Geology and Mineral Resources and Mr Ye Muqing, Engineer, Geology Survey Centre, accompanied by Madame Cai Wenyan their interpreter. There were also visits from various members of AFRC and DAFS staff during the year.

Visitors to the Institute who delivered lectures were:

Professor G.M. Hieftje, Department of Chemistry, Indiana University, USA, on "New Measurement Tools and Techniques in Chemistry" — this was the first delivery of the Royal Society of Chemistry's 1986 Redwood Lecture. Dr Paul H. Nadeau, Department of Earth Sciences, Dartmouth College, New Hampshire, USA, on "A Review of my Three Years at the Macaulay Institute"; Professor L.E. Lowe, Associate Dean and Professor of Soil Science, Faculty of Agricultural Sciences, University of British Columbia, Vancouver, Canada, on "Forms of Sulphur in Peats of the Fraser River Delta, BC"; Professor Alvin J.M. Smucker, Professor of Soil Biophysics in the Department of Crop and Soil Science, Michigan State University, USA on "Carbon Utilization by the Dynamic Plant Root System"; Dr H.K.J. Powell, Department of Chemistry, University of Canterbury, Christchurch, New Zealand on "Metal Complexation by Organic Molecules and Humic Materials".

Short-term visitors came to the Institute from twenty-one countries during the year and group visits included members from the Aberdeen and District Round Table, Aberdeen Probus Club, the Association of Civil Engineers, Scottish Oilfield Secretaries, Turriff Rotary Club and the Workers' Educational Association, as well as students from the Botany, Chemistry and Geography Departments of Aberdeen University, the Department of Physics of Dundee University, the School of Agriculture and the North of Scotland College of Agriculture. The Scottish Agricultural Librarians held their annual meeting at the Institute in May.

Long-term visitors were received from Canada, Spain, Sri Lanka the USA and the Federal Republic of Germany.

Honours and Appointments

Mr R.A. Robertson, Head of the Department of Peat and Forest Soils, was awarded the OBE in the Queen's Birthday Honours List.

Mr W.S. Shirreffs, Information Officer, has been invited to continue to serve on the Council of the British Cartographic Society Council.

Professor J.S. Bibby has had his period of appointment as Visiting Professor at Strathclyde University extended for a further period of three years.

Visits Overseas by Staff and Lecutres Given in Britain

Details of visits overseas by staff and of UK meetings where lectures were given are presented in Appendices II and III respectively.

Post-graduate Students

Mr Colin D. Campbell has now completed his experimental work for the degree of PhD and is currently writing up his thesis for submission to the University of Strathclyde.

Mrs Susan Lilly has submitted a thesis entitled "The distribution and ecology of morphological types of B. pendula (roth) and B. pubescens (ehrh)in Great Britain" to the University of Aberdeen, which has been sustained.

Institute Events

The Council of Management met five times during the year and SWAP meetings were held at MISR on various occasions. The MISR/COSAC Liaison Group held one meeting at the Institute in January 1986; the autumn meeting was postponed till early 1987.

Institute Caravan

During the year the Institute caravan was taken to the Royal Highland and Agricultural Show at Ingliston, Edinburgh, and to the Agricultural Shows at Ayr, Fife, Perth, Turriff and the Black Isle. The Institute was also represented and set up a display entitled "Optimizing nutrient supply to the potato crop" at the Royal Show at Stoneleigh.

Associates of the Institute

In recognition of their service as Heads of Departments, the Council of Management conferred the title of Honorary Research Associate of the Institute on Dr A.M. Ure and Mr R.A. Robertson on their retirement and on Mr R.H.E. Inkson who will retire in March 1987.

Programme Units and Research Objectives

The departmental responsibilities for individual Research Objectives in the Report are as follows:

1000 Mineral Soils
2000 Peat and Forest Soils
3000 Spectrochemistry
4000 Soil Organic Chemistry
5000 Plant Physiology
6000 Microbiology
7000 Soil Fertility
8000 Statistics
9000 Soil Survey

References

1. M.V. Cheshire, Profile 1986, **97**, 3
2. M.L. Berrow, Profile 1986, **100**, 5
3. B.L. Williams, Profile 1986, **100**, 7

PROGRAMME OF WORK

(1986)

PROGRAMME UNITS AND RESEARCH OBJECTIVES

PU 1: MINERAL SOILS: THEIR DEVELOPMENT, COMPOSITION AND PROPERTIES

RO

1001 Determine chemical and physical characteristics of Scottish soils, relevant to soil development and use.

1006 Characterize the composition of soil solution, soil atmosphere and stream water in relation to soil development, type and use.

1060 Determine the nature, origin and properties of the inorganic and organo-mineral constituents of Scottish soils.

1003 Determine surface and colloidal characteristics of soil particles in relation to soil chemical properties.

3005 Characterize soil mineral structures, surface properties and weathering by spectroscopic methods including IR, UV, Mössbauer and EPR.

1061 Weathering of minerals in Scottish soil and the availability of nutrient elements.

1062 Understand differences of properties and behaviour in various soil series and associations in Scotland.

1067 Relate mineral weathering to soil and freshwater acidification.

1075 Develop electron microscopic methods for the study of interactions at the root/soil interface.

PU 2: TRACE ELEMENTS: ORIGIN, DISTRIBUTION AND SPECIATION IN SOILS AND PLANTS IN RELATION TO EFFECTS IN AGRICULTURE

RO

3007 Establish geochemical and environmental origins, distribution and mobility of trace elements in Scottish soils.

3008 Determine effects of soil conditions on plant trace element uptake and distribution of trace elements in plant parts and species.

3803/ 4803 Determine forms of trace elements in soils, their interaction with organic substances and their transport mechanisms to the plant.

4068 Devise practical methods to remove pollutants from agricultural and industrial wastes.

3010 Develop multi-element analytical techniques using dc arc optical emission and spark source mass spectrometry for solids.

3011 Develop spectrochemical methods using atomic absorption and inductively coupled plasma emission spectrometry for solutions.

3069 Develop chemical and instrumental methods for trace element speciation in soils and plants.

3074 Develop and apply thermal ionisation mass spectrometry for the precise determination of elemental isotopic composition.

PU 3: SOIL SURVEY OF SCOTLAND

RO

9012 Survey and map the soils of Scotland and produce soil maps and accompanying descriptive literature.

9013 Produce interpretative maps.

9804/1804 Characterize structure-forming processes of Scottish soils in relation to their physical behaviour and properties.

9063 Monitor the soil moisture status of a number of the principal soils of Scotland.

9015 Establish a fundamental classification of plant communities by recording and mapping.

9016 Assess grazing quality of plant communities and changes caused by pressures of land use.

9070 Devise methods of national soil survey data management and modelling.

PU 4: NATURE AND PROPERTIES OF SOIL ORGANIC MATTER

RO

3017 Characterize soil organic matter by infrared and ultraviolet spectroscopy.

1018 Assess organic matter composition and development in natural and agricultural soils by analytical pyrolysis.

4019 Identify and measure organic nitrogen compounds in soil and establish the factors affecting their transformations.

4020 Determine the origins, nature and behaviour of polysaccharides in soil, and their effects on soil physical properties.

4021 Identify soil humic substances and examine their distribution and properties within soils and soil solutions.

3808/4808 Determine the function of organic matter in ameliorating trace element problems in soil.

4064 Extract organic constituents from soils and assess their effects on plant and microbial metabolism.

PU 5: ROLE OF MICROORGANISMS IN SOILS, ESPECIALLY IN SOIL/PLANT RELATIONSHIPS

RO

6025 Determine inter-relationships between soil actinomycetes, bacteria, protozoa and plant roots.

6026 Determine the inter-relationships between fungi and plant roots.

6027 Relate soil fertility and structure to microbial transformation of soil organic matter.

6028 Establish an understanding of the survival of fungi in soil and their transformation into soil organic matter.

6031 Determine the nature, distribution and metabolic activity of protozoa in soils.

PU 6: THE SURVEY, CHARACTERISATION AND MONITORING OF PEAT, LAND RESOURCES AND TERRAIN FEATURES

RO

2032 Apply environmental remote sensing techniques for resource survey and agricultural monitoring operations.

2033 Develop computer-aided methods for the integration and manipulation of spatial data.

2034 Provide an advisory and application centre for remote sensing within the AFRS and facilities for contractual research.

2035 Survey, classify and evaluate peat resources using ground-based, remote sensing and photogrammetric techniques.

2036 Characterize the physical and chemical nature of peat and peat products.

2065 Survey, map and monitor the distribution of bracken in Scotland.

2810/3810 Develop portable radiometers for monitoring crop cover, biomass and stress parameters.

PU 7: SOIL FACTORS AFFECTING CROP PRODUCTION

RO

7037 Quantify the availability of soil and fertiliser phosphorus to crops by chemical methods and field trials and assess interactions with acidity.

7038 Measure the ability of soils to provide sulphur to crops, and assess atmospheric sulphur inputs.

7039 Estimate mobility of soil native and applied nitrogen relative to water movements and crop uptake.

7041 Optimise crop yields by efficient control of lime, fertilisers and soil nutrient reserves.

7042 Determine the trace element balance in soils and crops and environmental conditions which affect availability.

7044 Investigate root growth in relation to the soil physical environment of contrasting soils and assess its importance to crop growth.

7045 Development of automated techniques for the analysis of soil extracts and solutions.

7046 Determine physicochemical factors which control availability of trace elements from soils to plants.

4801/9801 Determine mechanisms involved in ochre formation and devise methods of minimising its production.

7076 Assess the development of plant root systems especially in relation to nutrient demand.

7077 Characterize the genetic variation which exists and can be induced within important crops.

7078 Characterize the root-soil interface and its effects on nutrient and water supply.

PU 8: FACTORS AFFECTING CROP AND PLANT COMPOSITION

RO

7047 Relate the organic and inorganic constituents of crops to age and yield.

7048 Study the growth, development, nutrient accumulation and yield of field crops.

7049 Develop and apply radioactive isotope methods to soil-plant investigations.

5050 Characterize trace element uptake by roots and transport to shoots in electrochemical and metabolic terms.

5051 Characterize and compare the efficiency of uptake and transport of ammonium and nitrate ions.

5052 Determine nutrient interactions in trace element uptake by plants; implications for selection of pasture species.

5806/3806 Determine the forms of trace elements in plants with particular reference to dietary availability in animals and man.

4053 Determine the influence of environmental forces on plant growth and the physiological mechanisms involved.

5072 Determine the factors that affect the growth, productivity and morphology of Sphagnum.

7079 Assess the selenium content of food and fodder crops.

PU 9: NUTRITION AND DISTRIBUTION OF PLANTS AND PLANT COMMUNITIES ON ORGANIC AND OTHER MARGINAL SOILS IN SCOTLAND

RO

2054 Determine the effects of different management practices on biogeochemical cycling of elements in upland ecosystems.

2055 Determine the processes controlling nutrient immobilisation, mineralisation and availability in highly organic soils.

2056 Forecast nutritional requirements on marginal lands and prescribe remedial treatments for diagnosed deficiencies.

2807/6807 Identify the processes by which mixtures of different tree species enhance nitrogen availability in poor forest soils.

2066 Determine factors contributing to the passage of rainwater acidity into streams and suggest appropriate control measures.

PU10: STATISTICAL METHODS FOR SOIL-CROP RESEARCH AND DEVELOPMENT AND MANAGEMENT OF COMPUTER TECHNIQUES AND EQUIPMENT

RO

8057 Extend the range of experimental designs and methods of statistical analysis appropriate to soil research.

8058 Establish relationships which will show a closer dependence of crop responses on soil properties.

8059 Provide the computing facilities, both hardware and software, required in soil research.

1802/ 3802/ 8802/ 9802 Establish an information system for Scottish soils by means of data-base and statistical techniques.

PU11: THE IMPACT OF SOIL FACTORS AND VEGETATION ON THE ACIDIFICATION OF STREAM WATER

RO

2073 Determine changes in water composition on passage through forested and unforested sites and effects of K, Ca, Mg.

1809/ 2809/ 3809/ 4809/ Determine effects of soils and vegetation in modifying rain water chemistry and the acidification of streams and lakes.

1. MINERAL SOILS

M.J. WILSON

The work of the Department has continued to be concerned primarily with research into the fundamental factors controlling the physical and chemical characteristics of Scottish mineral soils in order to provide a rational basis for understanding their varied behaviour, mainly from an agricultural point of view. Up to the present time it has been possible to approach this work in a fairly comprehensive fashion and work has proceeded on soil analysis, soil inorganic, organic and organo-mineral constituents, the nature and reactivity of soil colloid surfaces, soil processes, for example, mineral weathering involved in plant nutrient release and sorption, and soil structure and texture. Because of staff cut backs, transfers and retirements, however, it will no longer be possible to maintain such an all-embracing approach. Undoubtedly, the work of the Department will require to be re-formulated afresh in order to participate fully and effectively in the new opportunities that will arise following the imminent setting up of the new Institute. Future work will concentrate on hill and upland situations and in this respect a useful start has been made by the Department's close involvement in the Surface Water Acidification Programme (SWAP) which is largely financed by funds administered by the Royal Society, the Norwegian Academy of Science and Letters and the Royal Swedish Academy of Sciences.

Staff have continued to collaborate with, and make available the specialized equipment and technical expertise within the department, to various organizations. These include other SARIs (Scottish Institute of Agricultural Engineering, Rowett Research Institute), the Scottish Colleges of Agriculture largely through the MISR/COSAC Liaison Committee and various Universities, particularly the University of Aberdeen. Further afield joint work has progressed with the Department of Agriculture of Northern Ireland, with the Soil Reference and Information Centre, Wageningen and the Centre for Industrial Research, Oslo. The last-named is in connection with SWAP and has facilitated the selection and instrumentation of a pristine catchment in Nord Trondelag, Norway as will be described later. Finally, work has continued to be done on a commercial basis for locally based companies including, for example, Redwood Corex, Robertson Research International, N.L. Baroid, SAI Tubular Services etc.

Members of staff have continued to serve on various committees, editorial boards and working groups. Dr M.J. Wilson was elected as Chairman of the Clay Mineral Group of the Mineralogical Society, serves on the Editorial Boards of Clay Minerals and Applied Clay Science, on the

Council of the British Society of Soil Science and on the British Standards Institution's Technical Committee on Soil Quality. Mr J.M. Bracewell is serving on the U.K. Organizing Committee of the 7th International Symposium on Analytical and Applied Pyrolysis. Dr D.C. Bain continues to serve as Secretary of the Clay Minerals Group and Assistant Editor of Clay Minerals, as does Mr B.F.L. Smith on the Committee of the Aberdeen Institute of Ecology.

During the year the Department was pleased to welcome Miss R. Perry who was appointed under SWAP on a fixed contract to assist in the analysis of rocks and soils sampled from various catchments.

Soil and Plant Analysis

Soil Analysis

The systematic chemical and physical analyses of soil profiles collected during the 1985 field season have been completed and almost half of those taken in 1986 have been analyzed. Soils have also been examined for other departments in the Institute and outside bodies such as other SARIs, British Coal and some oil-related companies. Currently, the Institute's Soil Database contains analytical data for almost 90% of all relevant profiles analyzed in the period 1976-1985 and over 80% of the National Inventory samples. A paper on the design of a database for Scottish soils in collaboration with the Departments of Statistics, Soil Survey and Spectrochemistry awaits publication[1]. Work has now been completed on the determination of the physical properties of six different soil types in north-east Scotland and the results will be discussed at the next meeting of the Working Group on Soil Physical conditions set up by the MISR/COSAC Liaison Committee. A laser-based automated particle size analyzer was acquired during the year, but because of lack of staff it has not as yet been possible to develop the full potential of the instrument. Work has continued on the determination of X-ray amorphous material in Scottish soils and a chapter describing the various techniques used has been prepared for a forthcoming book[2]. 1001, 9012, 1802

^{15} N Analysis

The existing SIRA 9 isotope mass spectrometer for ^{15} N analysis was replaced by the manufacturer in March due to its unsatisfactory performance. The replacement, an ANASIRA mass spectrometer coupled to a Carlo Erba combustion-type nitrogen analyzer has proved greatly superior. At a precision of 0.001 Atom % and repeatability of 0.001 Atom % (99% confidence) it operates more rapidly, at about 5 minutes per analysis, with automated sample introduction, and is more sensitive, accepting samples containing 50 to 150 μg N. Above all, being a combustion method, soil and plant material samples are accepted without the necessity of lengthy preprocessing to ammonium salts. Some 12,500 determinations p.a., equivalent to about 7,500 samples p.a. represents the rate achieved at

present. About 6000 samples have been processed from April to the year end. 2055, 5051, 6027, 7039, 7047

X-ray Fluorescence Analysis

XRF continues to demonstrate its versatility and ability to cope with a range of elements in different materials. During the year, about 2500 analyses for sulphur in herbage and crops were made mainly for the Departments of Soil Fertility and Microbiology, the Rowett Research Institute and Rothamsted Experimental Station. Other analyses performed include determination of aluminium in plant material for the Community Bureau of Reference of the EEC, determination of titanium in hay and cereal samples for the UKAEA and the analysis of major and minor elements in soils from an archaeological site in Lanarkshire for the Ancient Monuments Section of the Scottish Development Department. 7038, 6027

Thermoanalytical Studies

Thermoanalytical techniques are particularly suitable for evaluating poorly ordered soil materials and organic materials. Review articles[3,4] describing these applications still await publication. 1060, 1003

Inorganic Soil Constituents

Work has continued on the characterization of fine grained soil constituents, representing as they do the most reactive inorganic components by virtue of their large surface area. Such work has been a traditional strength of the Department in the past, but is now likely to receive rather less attention in the immediate future. Nevertheless, it is important to retain the capacity to conduct research into this area, not least because the chemical and physical nature of fine-grained soil minerals bear directly upon many important soil properties.

Clay Minerals

Work has continued on the characterization of clay materials that have been completely dispersed to what may be thought as their fundamental constituent particles. The dimensions of these particles from a variety of clay minerals have been measured by transmission electron microscopy and have been used to calculate parameters such as total surface area and charge density[5]. The results obtained agree reasonably well with independent determinations of these parameters and suggest that the dimensions of clay particles could relate to major soil physical properties. The development of a new conceptual model based on interparticle diffraction for the so-called interstratified clay minerals (described in Annual Report No. 54) has continued to arouse much attention. Earlier papers had concentrated almost exclusively on the physical nature of interstratified clays, but the latest contribution evaluates the chemical evidence from some smectites and

illitic clays[6]. Significantly, it was found that the amount of surface silicate charge balanced by non-exchangeable cations versus that balanced by exchangeable cations was about equal in most samples. This suggests that in interstratified illite-smectite the layer charge may not be asymmetrically disposed across the 2:1 silicate layer as previously thought, at least in the samples examined. Confirmation of these findings would undoubtedly support the new conceptual model for interstratified clays[7] which views swelling, as detected by X-ray diffraction, as being associated with the adsorption of organic molecules at the interfaces between exceedingly thin particles, rather than being necessarily associated with layers that are always chemically identical to smectite. This concept was also used in a collaborative study on sericite, — fine grained micaceous material — to explain its X-ray diffraction characteristics[8]. During the year a study on the unusual regularly interstratified mineral aliettite (talc — saponite) was mounted using complementary transmission electron microscopy and X-ray diffraction techniques. The results are consistent with those previously obtained for other regularly interstratified types. Aliettite will disperse to fundamental particles of ~20A in thickness and yet such a preparation diffracts as if it was made up of domains about 70-80A thick.

Much of the work on interstratified clays has been done on material from geological deposits. However, such minerals may be different to those found in soils, a point stressed in a paper soon to be published[9].

1060, 1061, 9012, 3005

Iron and Manganese Oxides

The hydrous oxides of iron and manganese represent very labile components in Scottish soils because of dissolution reactions involving both reduction and/or acidification. The latter factor was the subject of a collaborative review with the Department of Spectrochemistry that has now been accepted for publication[10]. The mineralogy of these oxides in soils can be rather variable and often depends crucially upon location within the soil profile. Detection of the subtle changes involved requires the complementary use of electron microscopy, microprobe analysis and X-ray diffraction[11]. In the manganese pans in freely drained gravels and coarse textured soils, for example, there is considerable variation in the mineralogy of the manganese oxides, with tunnel-structured manganates, such as hollandite and cryptomelane occurring in close proximity to layer-structured manganates such as lithiophorite and birnessite. This is important because it has been found that the accumulation of bioessential trace elements such as Cu and Ni have a greater affinity to the layer-structured minerals than to the tunnel-structured ones. The implications of these findings in relation to trace element availability are currently being assessed.

Studies on the ion-exchange properties of a synthetic layer-structured manganate have now been completed and the first two parts of this work on the exchange of alkylammonium cations, a reaction that can be used for diagnostic purposes, await publication[12,13]. Also awaiting publication is a

study of the iron oxide phases within an immature, alluvial soil profile[14] and, in conjunction with Dr R.M. Taylor, Division of Soils, CSIRO Australia, a paper aimed at confirming the presence of the so-called green rusts in poorly drained soils[15]. 1003, 1062, 3005

Other Minerals

In collaboration with the Department of Microbiology a review of the biominerals associated with crustose lichens has now been published[16]. Typically, a variety of oxalate minerals is found, but it has been suggested in the literature that the lichen acids will react with some primary rock-forming minerals to yield clay minerals such as halloysite and montmorillonite. The experiments described were repeated, but no clay minerals were found, despite extensive observations by transmission electron microscopy. A paper describing a new phosphate mineral, spheniscidite, in a soil profile in an area of nesting penguins on Elephant Island, British Antarctic Territory has now been published[17]. 1060, 6028

Organic and Biological Materials

The difficulty in examining soil organic materials and exploring their modes of transformation in the soil environment is essentially one of the complexity. The full biochemical analysis of a single sample is costly of time and resources and can leave a substantial fraction unidentified. One way round this problem is to choose a semi-empirical approach by adopting methods which are more readily applied to statistically significant numbers of soils, and which reflect in some way the essential biochemical composition as well as varying systematically with the transformation of organic matter (OM).

The application of analytical pyrolysis-mass spectrometry (Py-MS) combined with computerized multivariate analysis has, in recent years, proved a successful example of this approach[18], showing systematic variations of OM composition within temperate soil A and B horizons which are dependent on humification, illuviation and drainage factors. Papers on the B horizons[19] and on OM evolution in surface raw humus horizons[20] have been submitted and await publication.

The method has greater value than the straightforward provision of an empirical fingerprint of the OM. The nature of the mass ions in the composite low-voltage mass spectrum are often identifiable and specific to biopolymers such as polysaccharide, lignin and peptide. The back up technique of pyrolysis-gas chromatography-mass spectrometry (Py-GC-MS) is used to aid product identification. Thus the nature of the variation is seen semi-quantitatively in terms of changes in the gross biochemical composition.

A wider examination of OM in the environment by this method has shown a sample distribution which strongly suggests two main pathways of transformation, starting from the raw plant material. This is summarized in Fig. 1.1 which is a schematic representation of the sample distribution,

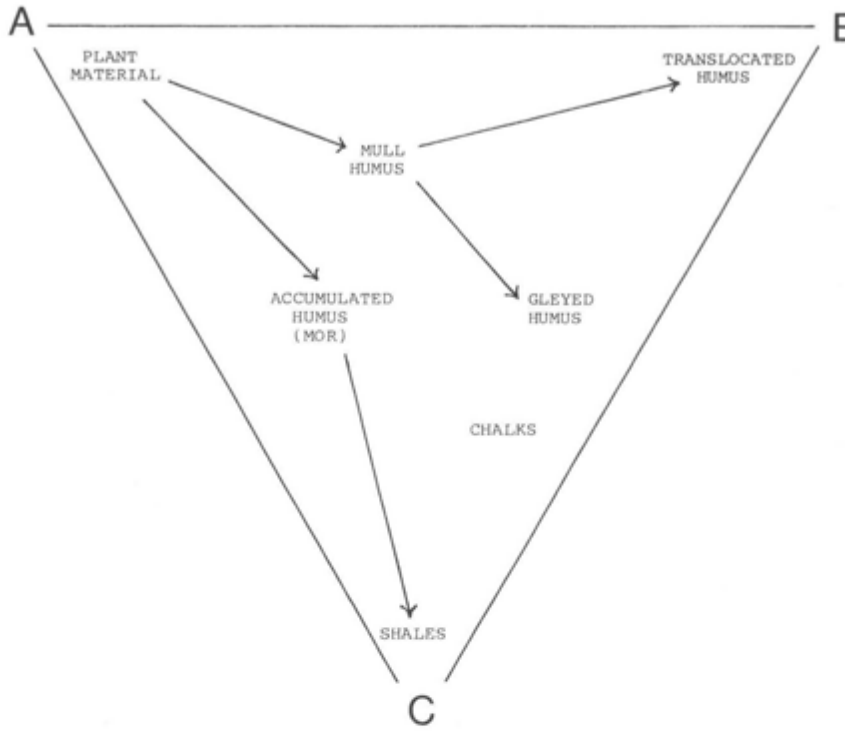
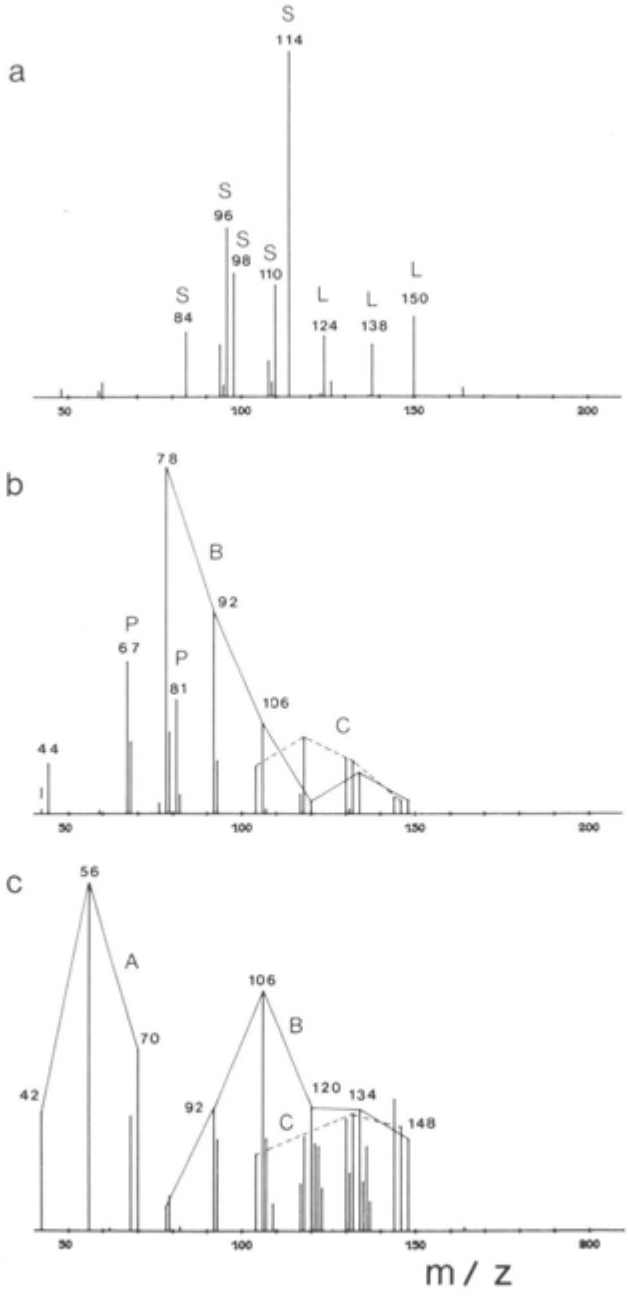


Fig. 1.1. Schematic of the distribution of samples containing organic matter from a wide variety of environmental sources. The diagram represents the first two principal components of a multivariate analysis using pyrolysis mass-spectra representative of 100 samples. (Only non-marine shales were examined).

plotted according to the first two principal components, and is derived from a multivariate analysis of Py-MS spectra drawn from a wide variety of sources within the environment.

Samples from the three corners are characterized by the generalized factor spectra shown in Fig. 1.2 which were reconstructed from the multivariate analysis. Thus, corner A contains the raw peat and L horizons, and the corresponding spectrum is highly characteristic of polysaccharide and lignin products. Transformed OM is shown by relative displacement towards the line BC and reflected in the spectra by loss of the characteristic polysaccharide and lignin products together with gain of hydrocarbon and other products. Normal rates of OM turnover in mineral soils are associated with displacement towards B, whilst retarded transformation corresponds to samples displaced in the C direction. Corner B is characterized by high levels of amino acid products and of benzene and toluene, whilst corner C (which is based on data only from freshwater shales) represents spectra high in alkenes and higher molecular weight hydrocarbons (Fig. 1.2). The major



Reconstructed factor spectra corresponding to directions in multivariate configuration space pointing to the corners of Fig. 1.1 (a) Corner A, (b) Corner B and (c) Corner C. Ions are derived from S – polysaccharides, L – lignins, P – amino acid residues, A – alkenes, B – alkyl benzenes and C – alkenyl benzenes.

division of mineral and organic soils are thus shown in terms of changes in basic biochemistry[21]. 1018

The effect of hydrolysis treatments on fulvic acids, to remove polysaccharide and peptide, was successfully monitored by Py-MS in joint work with the Departments of Soil Organic Chemistry and Spectrochemistry. Substantial agreement with IR and other analytical results was shown. This work should be extended using Py-GC-MS to identify pyrolysis products and obtain detailed structural information. The same applies to current Py-MS work on the transformations occurring in woods and barks from different tree species, carried out in conjunction with the Department of Microbiology. 1018, 4021, 6027

The identification of phenolic acids derived in a study of tree bark hydrolysates and of volatile terpenes from the headspace above incubated barks was carried out by GC-MS for the Department of Microbiology. Also for the same Department, various fungal metabolic products were identified including mycophenolic acid from *Penicillium Brevi-compactum*, and 5-hydroxymaltol plus an unknown of formula $C_{10}H_{10}O_3$. Molecular formulae were obtained by reference to high resolution mass spectrometers outwith the Institute. Other GC-MS separations and identification were produced for visiting research associates. 6027, 6028

Collaborative work with the Chemistry Department, University of Aberdeen has been carried out on the diagenetic evolution of OM in Cretaceous chalks[22], and with the U.S. Geological Survey on changes in the evolution of dissolved lake OM influenced by the Mount St. Helens volcanic eruption[23]. The project with the World Soils Collection, Wageningen, Netherlands has been discontinued due to the change of Institute organization. 1018

Surface and Physical Characteristics of Soils

Cs Sorption by Minerals

Following the realization that upland areas in Northern Britain had been contaminated with ^{137}Cs and ^{134}Cs resulting from the fall-out after the Chernobyl accident, the Department was invited to collaborate with the Rowett Research Institute and others in a project aimed at increasing the rate of loss of radiocaesium from contaminated lambs. The means by which this could be accomplished lies in certain minerals and synthetic compounds possessing a marked selectivity for the Cs ion. It was thought that the incorporation of these minerals into animal feeds might produce the desired accelerated removal of Cs. Alternatively, treatment of the contaminated herbage with appropriate minerals might serve to reduce Cs uptake in the first place. A series of sorption experiments were carried out in an attempt to simulate the exchange processes likely to occur within the intestines of sheep. The four sorbents chosen for these experiments were the clay materials bentonite and hydrobiotite, the zeolite mineral clinoptilolite and a synthetic ferrocyanide complex (K_2 [$COFe(CN)_6$]). Sorption isotherms for Cs were determined in an equimolar Na/K chloride solution at pH 6.5, first by analyzing the sorbents for Cs by XRF and then by determining solution

concentrations before and after equilibration. The order for selectivity was established as Ferrocyanide > Clinoptilolite > Hydrobiotite > Bentonite. The ferrocyanide was by far the best sorbent and effectively removed all Cs up to the 1OO ppm level for a solid: liquid ratio of 1:100. Uptake varies with the solid-to-liquid ratio, but the actual amount taken up will be constant up to 15 mg/g Cs leaving no appreciable Cs in solution. The minerals generally left some 50% of the added Cs in solution, even at the 10 ppm level.

Another factor to be considered in any treatment is the possibility of release of sorbed Cs as the sorbent passes through the intestines of the sheep and is exposed to acidic conditions. An experiment designed to determine the desorption of Cs at pH 3.O showed again that the ferrocyanide complex was the most stable and only 7% of sorbed Cs was released after prolonged periods. Clinoptilolite released 16% of its sorbed Cs in the same conditions, hydrobiotite 25% and bentonite 63%. It is encouraging that work at the Rowett Institute confirms that both the ferrocyanide complex and the clinoptilolite increase the rate of explusion of radiocaesium from contaminated lambs. 1003

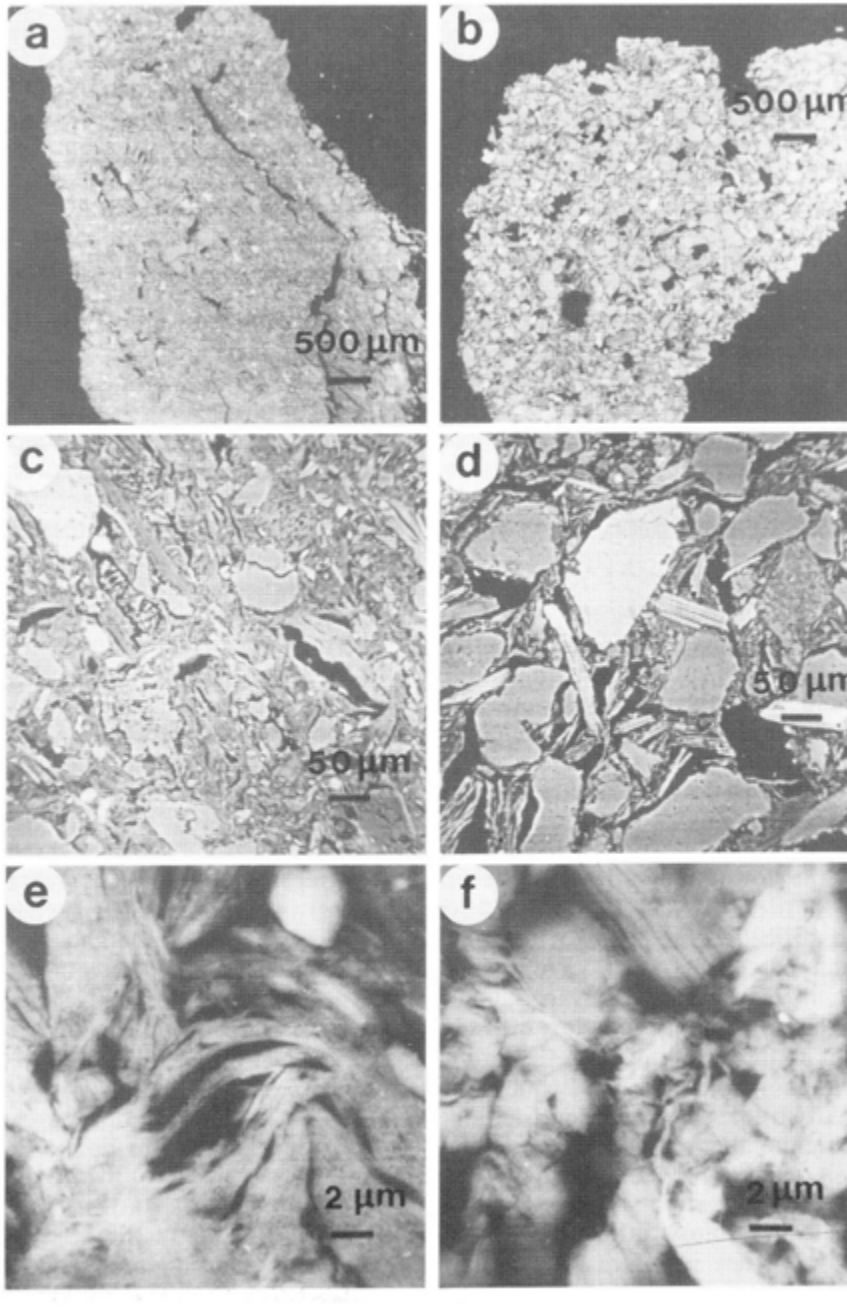
Physical Properties of Soils

The use of backscattered electron imaging in the scanning electron microscope as an aid in the assessment of the structure and physical properties of soils is providing more readily interpretable information than could be obtained previously. In particular, a more objective assessment of pore size, pore size distribution and general microfabric is readily attained. Fig. 1.3 shows the structure of two soil aggregates, one of which has been treated with polyacrylamide solution the other being untreated. The treated aggregate remains intact when immersed in water, whereas the untreated aggregates disintegrates immediately. It is obvious from Fig. 1.3e and d that at the lower magnification the control aggregate has a much greater proportion of large pores (50 μm or less) whereas at the highest magnification the porosity in the micrometer range seems to be about the same (Fig. 1.3e and f). From these observations it seems likely that the stabilizing effect of polyacrylamide works by filling the larger pores, or possibly induces a secondary effect by causing swelling of the clay minerals. 1804

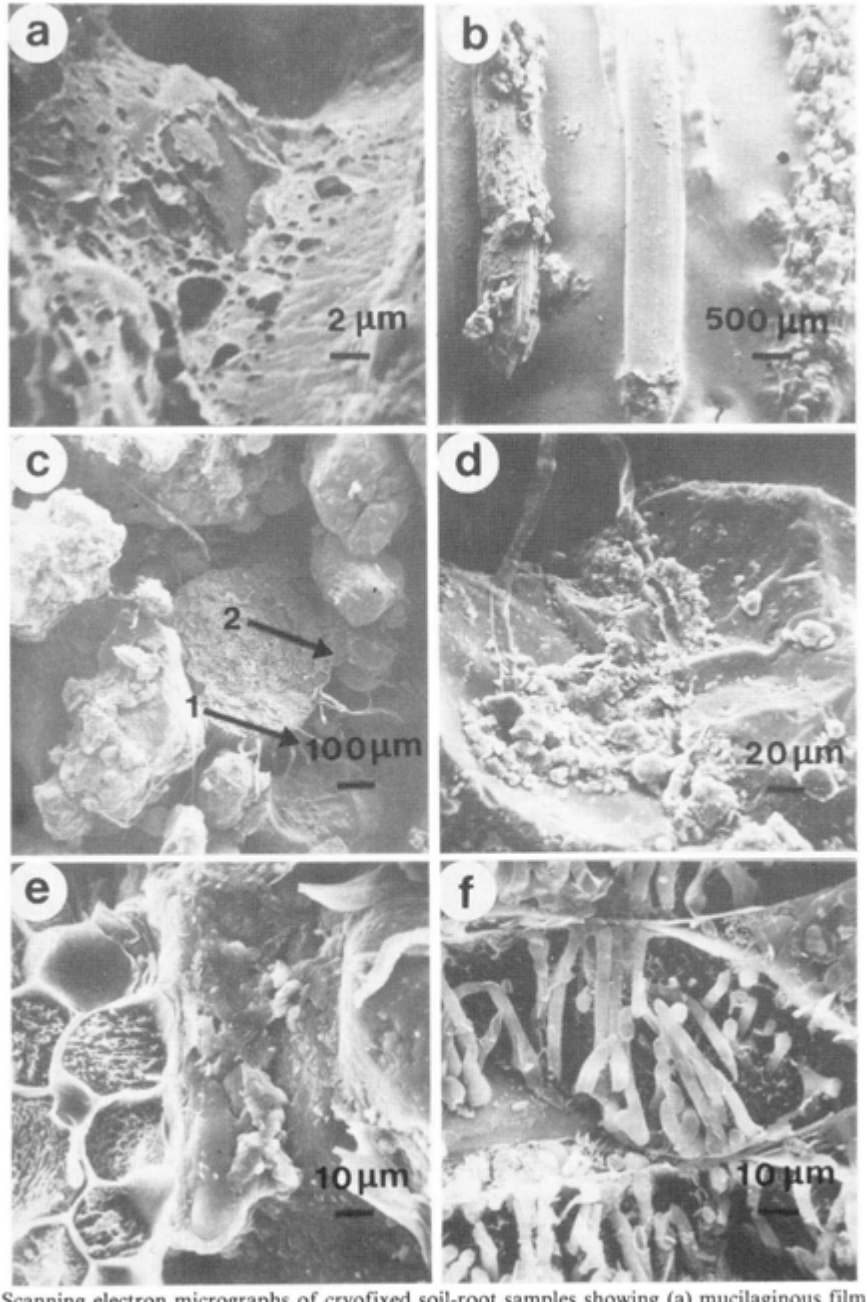
Scanning Electron Microscopy

The Soil-Root Interface

In collaboration with the Department of Soil Fertility, a start has been made on the application of low temperature SEM techniques to the study of the soil-root interface, the initial objective being the optimization of specimen preparation and the recognition of specific features. Initital results using barley as a test plant are extremely encouraging. For example, in some preparations a mucilaginous film is readily observed, extending a considerable distance from the root itself (Fig. 1.4a). The binding effect of



Scanning electron micrograph in the back-scattered electron imaging mode of soil aggregates treated with polyacrylamide stabilizer (a, c and e) and in the untreated state (b, d and f).



Scanning electron micrographs of cryofixed soil-root samples showing (a) mucilaginous film extending from a root into the soil, (b) retention of soil after washing on middle aged, young and old roots (left to right), (c) cross-fractured frozen root surrounded by loose soil particles, (d) detail of (c) showing root hairs adhering to sand grain through association with fine clay material. (e) detail of (c) showing intimate contact between root and soild and (f) invasion of root cells by fungal hyphae.

this mucilage on soil particles is greatest in relatively old roots as shown in Fig. 1.4b.

Cross fracture of the frozen root with its adhering soil also revealed features of interest. Following fracture, the surface is generally etched for 2 minutes at $-80°C$ and 10^{-3} Pa, a procedure which reveals the cell structure and arrangement much more clearly. Although there is clearly much pore space immediately adjacent to the root surface (Fig. 1.4c), higher magnification reveals root hairs attached to sand grains by means of adhering fine material (Fig. 1.4d). Another point of intimate soil-root contact is illustrated in Fig. 1.4e. Sometimes, fractured root preparations reveal how the cells have been invaded by fungal hyphae (Fig. 1.4f).

Mycorrhiza

In collaboration with the Department of Microbiology, scanning electron microscopy has been used in a study of mycorrhizal involvement in tree nutrition. Fig. 1.5 shows a partially etched cross fracture of a frozen, hydrated mycorrhizal root of Sitka Spruce in which the root is enveloped by a tightly woven fungal mycelium, which also penetrates between the cortical cells — this constitutes the so-called Hartig net. The figure is a montage of eighteen micrographs and won first prize in a micrograph competition held in conjunction with the 14th Scottish Symposium on Electron Microscope Techniques. Several short papers describing this work in more detail have been published[24–26]. 6026

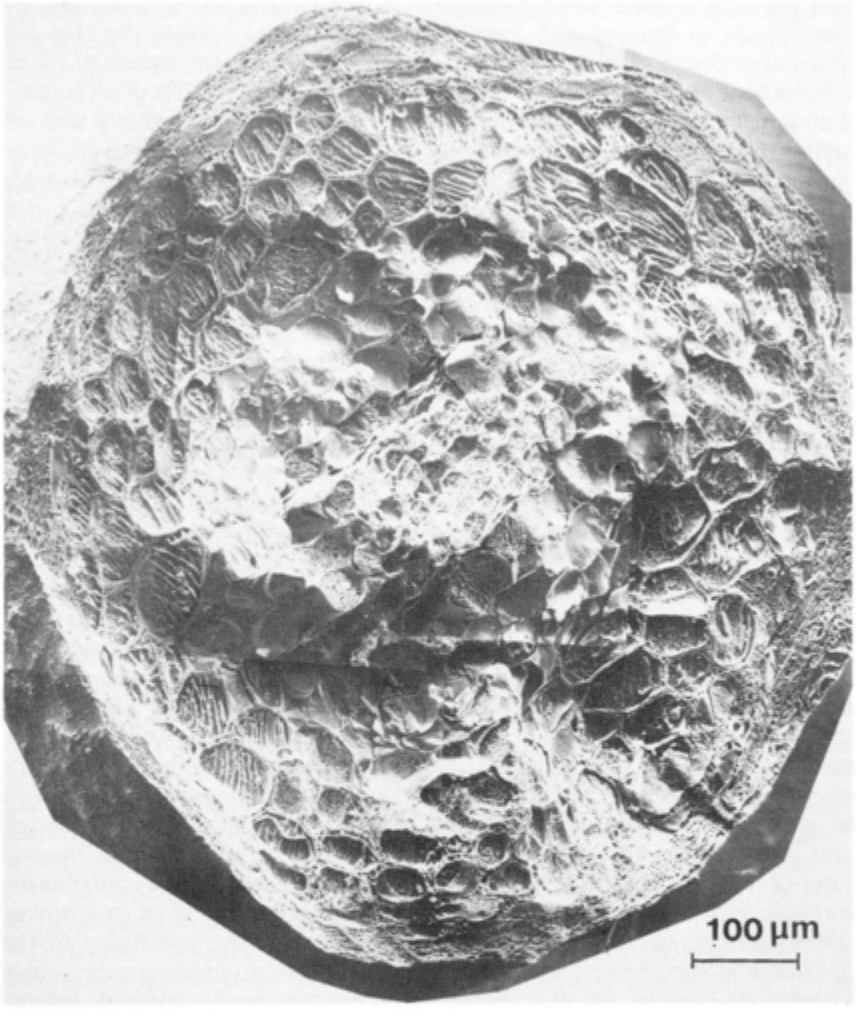
SEM and Sulphur Applications

Low temperature SEM with microprobe analysis has been used to follow with time the fate of sulphur applied to peas in a foliar spray. 5 mm diameter cores, sometimes from the same leaf, were taken at regular intervals over a period of two months from two plants, one kept outdoors the other in a greenhouse. There was no noticeable overall loss of sulphur from the leaf surface of the indoor plant right up to the time of die-back. The outdoor plant behaved similarly while the weather was dry, but sulphur was totally lost from the leaf surface after a period of rain. This work was done in collaboration with the Department of Soil Fertility. 7038

Soil Processes

Pedogenesis and Trace Elements

Investigations into mineralogical variations in hydrologic sequences where the amounts of extractable trace elements vary according to drainage status have continued. In collaboration with the Department of Spectrochemistry, sequential extractions involving water, ammonium acetate, acetic acid and EDTA have been made on four subsoils containing the same total Cu content, but with varying Cu extractability. The latter increased with drainage impedance and in the two most poorly drained soils



Montage of eighteen scanning electron micrographs of etched cross-fracture of frozen mycorrhizal root of Sitka spruce. Note the penetration of the cortical cells by the surrounding tightly woven, fungal mycelium (Hartig net).

more than half the extractable Cu was removed by water and ammonium acetate, suggesting an association with the exchange complex. In contrast, in the most freely drained soils about 70% of the extractable copper was removed only by acetic acid and EDTA, suggesting that the metal is more strongly bound. It is not yet clear how these results can be accounted for. The soils themselves are derived from micaceous schist (Strichen Association) and contain considerable amounts of layer silicate material, particularly in the clay fractions which may contain up to 10 times more

total Cu than in the coarser fraction. It is known that biotite is a common host for Cu in igneous and metamorphic rocks and it could be that the differences described above relate to biotite weathering, the nature of which is dependent upon drainage conditions. Certainly, the clay fractions contain abundant biotite-derived material such as hydrobiotite and vermiculite. A similar pattern of Cu extractability also occurs in soils derived from Caithness flagstones (Thurso Association) and from weakly metamorphosed Palaeozoic sediments (Ettrick Association). Again, the clay fractions are dominated by vermiculitic weathering products, although these are not derived from biotite as far as is known. 1061, 1062, 3007

Loch Fleet Experiment

This experiment which is organized and sponsored by the electricity generating industry has the overall objective of demonstrating that the water chemistry of the loch can be brought into a range suitable for a self-sustaining trout population by suitable manipulative treatment of the catchment area. At present the loch is too acid to be able to support fish. The involvement of the Department has been to characterize and monitor the nature of the seepage waters around the periphery of the loch by means of porous cup tension lysimeters installed at 30 cm depth and to investigate the chemistry and mineralogy of the catchment soils, particularly to elucidate the processes involved in the release of aluminium from the soil. Base-line water chemistry data were acquired prior to the application of lime to three well-defined sectors of the catchment. It was found, in particular, that the pH, silica and aluminium were distinctly higher in the soil water than in the streams whilst the reverse was true for sulphate. With the application of lime, calcium and pH rose dramatically in the stream (and loch) water, but so far there has been little or no change in the soil water chemistry. This suggests that the soil seepage waters are contributing relatively little to the loch waters, at least during the period of monitoring which was one of heavy rainfall. On the contrary, the hydrology of the catchment is dominated by overland flow in these circumstances, firm evidence in favour of this proposition having been acquired by the Department of Peat and Forest Soils.

The soils of the catchment are usually highly organic, acid and with low base saturation percentages. The exchange acidity of both organic and mineral soils and the contribution of aluminium to this acidity was measured with a neutral salt. The results show that the highest values occur in the organic soils, although the greatest contribution of aluminium to the exchange acidity occurs in inorganic horizons.

The work on mineral weathering was constrained by the predominantly organic nature of the Loch Fleet Soils. Nevertheless, in the few mineral soils that could be examined, the involvement of mineral weathering (which is of course the ultimate source of the soil aluminium) in the release and trapping of aluminium was quite clear. Particular points of interest were the intensely corroded nature of the feldspars separated from the organic

horizons and in the B horizon the vermiculitization of aluminous mica with concomitant formation of hydroxyaluminium interlayers. 1060, 1067

Surface Water Acidification Programme (SWAP)

The Department's involvement in this work is focussed on the interactions between soil waters, the exchange complex and mineral weathering, particularly with a view to determining the effects of these factors on the acidification of streams. Three catchments have been selected for study in Scotland as part of SWAP, these being at Allt a Mharcaidh in the Cairngorms and at Loch Chon and Kelty Water near Loch Ard. The chemistry of the soil waters in these catchments, both in the experimental plots set up by the Department of Peat and Forest Soils and at other selected points, are being monitored on a monthly basis using porous cup lysimeters. Hopefully, the results will provide some insight into the effects of different geological parent materials (granite versus mica schists) and soil types and will also form a useful comparison with the soil waters being collected in the experimental plots by means of gutter-type lysimeters (unsaturated versus saturated flow). A major part of the work will concern the effect of sulphate and work is under way to measure a) the amount of sulphate already present in the soil b) adsorption maxima for sulphate and c) the pH and concentration dependency of sulphate sorption-desorption. This work may help to predict how easily sulphate will continue to be removed from the catchment soils following the reduction of emissions. Leaching experiments have also been set up on selected soils to compare the relative effects of percolating water, organic and mineral acids on the removal of Al, the type of Al removed, the leaching of indigenous sulphate, and the loss of exchangeable cations with the consequent effect on the soils' buffering capacity. Also well under way is the work on weathering and soil mineralogy. Soils, weathered rocks and rocks have been collected from the three catchments and many have been characterized, in terms of their chemical and mineralogical composition as determined by XRF and XRD respectively. From the results available, it is clear that the overall soil clay mineralogy at the three catchments clearly reflects the influence of the underlying bedrock with mica, vermiculite, kaolinite, gibbsite and feldspars being prominent at Allt a Mharcaidh compared with mica, chlorite and quartz at Loch Chon and Kelty Water. Chlorite weathering is an important process, particularly in the podzols of the latter catchments, and in all soils the formation of a dioctahedral aluminous vermiculite, which is often interlayered with hydroxyaluminium in the B horizons, is a common feature. Furthermore, collaborative studies with the Department of Spectrochemistry reveal the occurrence of significant amounts of allophanic/imogolitic material in the Bs horizons of Allt a Mharcaidh but not in the soils of the other catchments. The alpine podzols in the Allt a Mharcaidh catchment also contain substantial amounts of gibbsite. These findings are intriguing because they present the opportunity to determine the influence of different aluminous minerals on the aluminium chemistry of the soil and stream waters.

During the year an obvious gap in SWAP was filled by the selection of a pristine catchment, in collaboration with our Norwegian colleagues, at Høylandet, Nord Trondelag, Norway. A party from the Peat and Forest Soils and Soil Organic Chemistry Departments later set up experimental plots in the same way as for the other SWAP catchments and collected soil and rock samples. The catchment itself is situated in an area of acid gneisses (with basic inclusions), is forested and dominated by well-developed podzol soils. Research on the mineralogy and chemistry of the soils will be carried out in the same way as described above. During the year a paper outlining the mineral weathering processes in podzol soils developed on granite and the implications for surface water acidification was published[27].

1067, 1809, 3005

Mountain Soils

Localized occurrences of gibbsite, an aluminium hydroxide mineral, in the C horizons of Scottish montane soils have been previously interpreted as relict features related to Tertiary weathering. To establish whether gibbsite was of general occurrence in these soils, the clay fractions separated from the C horizons of thirty four selected profiles from montane sites were examined by thermoanalytical methods. Gibbsite was detected in over half the samples at levels >1%, with twelve samples possessing in excess of 10%. Sand-sized grains in some profiles were intensely corroded and gibbsitized, as proved by microprobe analysis and X-ray powder photography. Other deep weathering sites in the Grampian and Cairngorm uplands were also examined during the year. Many of the samples collected contained abundant halloysite, another mineral thought to be indicative of weathering under climatic conditions warmer than those prevailing at present. Several papers have been published or accepted for publication on the pedogenesis of Norwegian arctic-alpine soils, this work having been done at the University of Hull[28–31].

1061

Biological Weathering

In collaboration with the Department of Microbiology, a paper has been published describing the weathering of basalt, serpentinite, granite and other rock types by crustose lichens[32]. Work aimed at confirming the reported synthesis of clay minerals by reacting lichen acids with various primary minerals was unsuccessful.

1061, 6028

Foreign Soils

A collaborative study with the University of Nsukka, Nigeria of the relationship between exchangeable bases and mineralogy of some selected Nigerian soils has been accepted for publication[33]. Although the soils are predominantly kaolinitic, they also contain appreciable amounts of expansible minerals. The amounts of clay minerals which occur in aggregated grains in the sand fraction correlate strongly with the various

individual exchangeable cations, but there is no such relationship in the finer particle sizes. 1060

Development of Methods and other Work

Two papers have been published on refinements in methodology and application regarding X-ray diffraction and transmission electron microscopy during the year. A method has been described for preparing randomly oriented clay mounts on glass slides[34] and a semi-micro method has been developed enabling heterogeneously distributed soil components to be sampled and examined by electron microscopy[35]. A review paper written in collaboration with the Department of Spectrochemistry and the Director describing the application of optical, electron and X-ray spectrometry methods to problems in soils analysis[36] has also been published. Work has continued with the Edward Davies Chemical Laboratories, University College of Wales, Aberystwyth on the possible uses of synthetic randomly interstratified clays as catalysts. A paper describing other possible industrial and commercial applications of highly dispersed clay materials has been accepted for publication[37] and a chapter describing the use of chemical methods in the characterization of clays has been written[38].

Other papers accepted for publication during the year are concerned with a further elaboration of the concept of fundamental clay particles[39] and, in collaboration with the Department of Microbiology, the characterization by X-ray diffraction of a crystalline antibiotic product — vermiculine — associated with a cultured fungus[40,41]. 1003, 1060, 1061, 3010, 3011, 6026

References

1. Design of a database for Scottish soils. By K.W.M. Brown, J.H. Gauld, B.F.L. Smith, D.C. Bain, J.C. Burridge and R.H.E. Inkson. To appear in Journal of Soil Science.
2. Characterization of poorly ordered minerals by selective chemical methods. By B.F.L. Smith and B.D. Mitchell. To appear in Determinative Methods in Clay Mineralogy. Edited by M.J. Wilson. Blackie & Son, Glasgow.
3. Complementary Techniques. By R.C. Mackenzie. To appear in Thermogravimetry. Edited by R.P. Redfern and C.J. Keattch. Chichester, Wiley.
4. Application of thermogravimetry to naturally occurring organic materials. By E. Paterson and B.D. Mitchell. To appear in Thermogravimetry. Edited by J.P. Redfern and C.J. Keattch.
5. The physical dimensions of fundamental particles. By P.H. Nadeau. Clay Minerals *20*, 499-514, 1985.
6. Composition of some smectites and diagenetic illitic clays and implications for their origin. By P.H. Nadeau and D.C. Bain. Clays and Clay Minerals *34*, 455-464, 1986.
7. Are interestratified clay minerals aggregates of very thin crystals? By W.J. McHardy in Clay Minerals and the Origin of Life. Edited by

A.G. Cairns-Smith and H. Hartman. Cambridge University Press, 1986.

8. Sericite. By D.D. Eberl (U.S. Geological Survey), J. Sroden (Polish Academy of Sciences), P.H. Nadeau, R. Northrop (U.S. Geological Survey) and Mingchou Lee (Case Western Reserve University). Submitted to American Mineralogist.
9. Soil smectites and associated interstratified minerals: recent developments. By M.J. Wilson. To appear in Proceedings of the 1985 International Clay Conference, Denver, USA.
10. The effect of pH on the chemistry of manganese, iron and aluminium oxides. By V.C. Farmer, B.A. Goodman and E. Paterson. To appear in Proceedings of the 12th International Soil Science Congress, Hamburg, West Germany.
11. The mineralogy and morphology of iron and manganese oxides in an imperfectly drained Scottish soil. By A.C. Birnie and E. Paterson. To appear in Geoderma.
12. Cation exchange in synthetic manganates. Part I. Alkylammonium exchange in synthetic phyllomanganate. By E. Paterson, J.L. Bunch and D.R. Clark. To appear in Clay Minerals.
13. Cation exchange in synthetic manganates. Part II. The structure of an alkylammonium-saturated phyllomanganate. By E. Paterson, D.R. Clark, J.D. Russell and R. Swaffield. To appear in Clay Minerals.
14. Transport and precipitation of iron in a poorly drained, alluvial soil. By E. Paterson, J.H. Gauld and D.R Clark. To appear in Journal of Soil Science.
15. Does green rust occur in soils? Problems in location and identification. By R.M. Taylor, G. Brummer, (CSIRO, Adelaide Australia) E. Paterson and D.R. Clark. To appear in Australian Journal of Soil Research.
16. Biomineralization in crustose lichens. By D. Jones and M.J. Wilson in the Systematics Association Symposium on Biomineralization in Lower Plants and Animals. Oxford University Press, Oxford. Chapter 6, 91-105, 1986.
17. Speniscidite, a new phosphate mineral from Elephant Island, British Antarctic Territory. By M.J. Wilson and D.C. Bain. Mineralogical Magazine, *50*, 291-293, 1986.
18. Thermal degradation of humic substances relevant to structural studies. By J.M. Bracewell, K. Haider, S.R. Larter and H.R. Schulten. To appear in "Humic Substances II; in Search of Structure". Editors M.H.B. Hayes, R.L. Malcolm and R.S. Swift, Wiley, New York.
19. Characteristics of soil organic matter in temperate soils by Curie-point pyrolysis-mass spectrometry. II. The effect of drainage and illuviation in the B horizons. By J.M. Bracewell and G.W. Robertson. To appear in Journal of Soil Science.
20. Characteristics of soil organic matter in temperate soils by Curie-point pyrolysis-mass spectrometry. III Transformations occurring in

surface organic horizons. By J.M. Bracewell and G.W. Robertson submitted to Geoderma.

21. Class characteristics of the principal groups of organic materials in terrestrial and aquatic environments by analytical pryolysis. By J.M. Bracewell and G.W. Robertson. Submitted to Journal of Analytical and Applied Pyrolysis.
22. Organic matter from onshore Cretaceous chalks and its variations, investigated by pyrolysis mass spectrometry. By J.M. Bracewell, N. Pacey and G.W. Robertson. To appear in Journal of Analytical and Applied Pyrolysis.
23. Long term oxidative changes in dissolved humic substances in Spirit Lake and South Fork Castle Lake, Washington. By D.M. McKnight, K.A. Thorn, R.L. Wershaw, J.M. Bracewell and G.W. Robertson. Submitted to the Journal of Limnology and Oceanography.
24. SEM of cryofixed mycorrhizas. By D. Jones, Clare Alexander and W.J. McHardy. Abstracts XIV International Congress of Microbiology, Manchester *149*, 1986.
25. Scanning electron microscopy of cryofixed mycorrhiza of Sitka Spruce (*Picea sitchensis*) and other selected mycological specimens. By D. Jones, Clare Alexander and W.J. McHardy. Proceedings of the Royal Microscopical Society *21*, 587, 1986.
26. Scanning electron microscopy of cryofixed Sitka spruce mycorrhiza: a comparison with critical point dried material. By Clare Alexander, D. Jones and W.J. McHardy. To appear in New Phytologist.
27. Mineral weathering processes in podzolic soils on granitic materials and their implications for surface water acidification. By M.J. Wilson. Journal of the Geological Society, London, *143*, 691-697.
28. Textural and scanning electron microscope observations of some arctic-alpine soils developed in Weichselian and Neoglacial till deposits in southern Norway. By A. Mellor. Arctic and Alpine Research *18*, 327-336, 1986.
29. Hydrobiotite formation in some Norwegian arctic-alpine soils developed in Neoglacial till. By A. Mellor. Norsk Geologisk Tidsskrift *66*, 184-185, 1986.
30. A micromorphological examination of two alpine soil chronosequences, southern Norway. By A. Mellor. To appear in Geoderma.
31. A pedogenic investigation of some soil chronosequences on Neoglacial moraine ridges, southern Norway; examination of soil chemical data using principal components analysis. By A. Mellor. To appear in Catena.
32. Biological weathering of Minerals. By M.J. Wilson and D. Jones. Minerali Argillosi ed Ossidi di Ferro del Suolo". Societa Italiana della Scienza del Suola. Association Internationale pour L'Etude des Argiles (Gruppo Italiano), 57-65, 1985.
33. Some aspects of the mineralogy and nutrient status of some selected Nigerian soils. By I. Unamba-Oparah, M.J. Wilson and B.F.L. Smith. To be published in Applied Clay Science.

34. Preparation of randomly orientated samples for X-ray diffractometry. By E. Paterson, J.L. Bunch and D.M.L. Duthie. Clay Minerals *21*, 101-106, 1986.
35. A semi micro method for the examination of selected soil components by transmission electron micrscopy. By A.C. Birnie, D.R. Clark and E. Paterson. Clay Minerals *21*, 231-234, 1986.
36. Optical, electron and X-ray spectrometry in soil analysis. By D.C. Bain, M.L. Berrow, W.J. McHardy, E. Paterson, J.D. Russell, B.L. Sharp, A.M. Ure and T.S. West. Analytica Chimica Acta *8O*, 163-185, 1986.
37. Clay particle engineering: a potential new technology with diverse applications. By P.H. Nadeau. To be published in Applied Clay Science.
38. Chemical Analysis. By D.C. Bain and B.F.L. Smith. To appear in Determinative Methods in Clay Mineralogy. Edited by M.J. Wilson. Blackie & Son, Glasgow.
39. The fundamental nature of interstratified illite-smectite clay particles — a reply. By P.H. Nadeau, M.J. Wilson, W.J. McHardy and Tait. To appear in Clays and Clay Minerals.
40. Scanning electron microscopy and X-ray powder diffraction of crystals of the microlide dilactone antibiotic, vermiculine, accumulating in shake cultures of *Talaromyces wortmannii*. By D. Jones and M.J. Wilson. To appear in Transactions of the British Mycological Society.
41. Characterization of crystals of vermiculine from shake cultures of *Talaromyces wortmannii*. By D. Jones, M.J. Wilson and J.D. Russell. Abstracts, XIV International Congress of Microbiology, Manchester 245, 1986.

2. PEAT AND FOREST SOILS

R.V. BIRNIE

The research programme of the Department is broadly concerned with the study of highly organic soils in Scotland. This involves the development and application of survey techniques for assessing the extent and quality of the peatland resource, and more detailed chemical studies on nutrient pathways through organic soils under different management regimes, particularly under grassland and forestry. In recent years, research on new methods for resource surveying, especially those based on remotely sensed data, has led to the Department widening its research objectives to include more general environmental monitoring. Likewise, the considerable field and laboratory expertise gained in studies of forest nutrition over the past twenty years, has allowed the Department to develop new collaborative programmes on environmental water chemistry and the problems of surface water acidification.

There is a continued demand for information on the suitability of particular peat bogs for production of horticultural or fuel-peat products. Where possible, this information is provided from existing records. If the bogs have not been previously surveyed large scale field surveys are undertaken. The efficiency of these surveys has been improved through the use of electronic distance measuring devices and digital cartographic facilities in the production of the survey maps. Increasingly these large scale surveys are done under contract to external agencies. Much of this work is done in close association with the Highlands and Islands Development Board, the Scottish Development Agency, the Scottish Development Department, the UK Peat Producers Association, the Forestry Commission, the Nature Conservancy Council and other organisations in both the public and private sectors.

The remote sensing programme is primarily concerned with the development of methods for applying remotely sensed data to environmental monitoring problems. Much of the early research was directed towards peat survey applications, but the work has been widened to cover both resource surveys and agricultural monitoring. The latter has been based on the central concept of agricultural problems being scale-dependent. Thus large area crop mapping programmes have been appropriately tackled using satellite imagery, whilst detailed crop monitoring has been achieved through the development of ground radiometry. Likewise it has also been recognised that not all the necessary information may be obtained from one source, thus the remote sensing

programme has included the development of methods for integrating image data with existing map information. Excellent progress continues to be made in the application of these methods. Examples can be seen in the peatland map of the Shetland Islands, the first map to be produced entirely by digital cartographic methods, and based on a combination of field survey and satellite image data. Work on the potato crop distribution in eastern Scotland, based on a combination of satellite imagery and digitised maps, has provided new information on the proportion of the crop being exposed to drought-risk. Likewise detailed crop radiometric measurements over winter oilseed rape trials have highlighted the growth effects of pre- and post-emergence herbicide treatments and their implications for increasing susceptibility of soil to water erosion in the autumn/early winter period. Much of this progress has largely been achieved through close collaboration with the North of Scotland College of Agriculture, the Scottish Crop Research Institute and Aberdeen University. Links are also maintained with the National Remote Sensing Centre, RAE Farnborough for which the Institute acts as a Regional Centre, the European Space Agency, the Department of Industry, RSRE Malvern, the Scottish Development Department, Silsoe College, and the Universities of Dundee (Physics), Edinburgh (Geography) and Glasgow (Topographic Sciences).

The research programmes aimed at investigating the nutrient pathways and fluxes in various soil/plant systems have continued to produce valuable information. A major report to the Commission of the European Community on the use of mixed species to improve the nitrogen nutrition of Sitka spruce has been completed. This has highlighted some of the factors which are responsible for the improved growth of spruce under mixed species conditions. Three major water chemistry monitoring programmes have been ongoing. The first is directed towards examining the effects of afforestation/deforestation on water quality and quantity, the other two are more directly concerned with acid rain and form part of collaborative programmes funded by the Department of the Environment and The Royal Society respectively. All of these programmes are based on routine water sampling at various points through rainwater/plant/soil pathways. Chemical analyses for major anions and cations are subsequently done within the Department. Because of the large number of samples involved, an ion chromatograph has been installed and an estimated 10,000 samples can now be analysed per annum. Development and application of computer modelling to forest nutrition has continued, and a new project to examine nutrient cycling in second rotation stands has begun in collaboration with the Forestry Commission. A forest Nursery Advisory Service continues to be provided. Research on nitrogen availability and uptake on poorly drained peatland reseeds in Sutherland has provided new information on the processes of denitrification and immobilization of N in deep peat which has important implications to fertilisation procedures for improving Scottish peatlands. Many of these projects are co-operative and involve external organisations which include the Forestry Commission (Research and Development Division), the Irish Forest and Wildlife Service in association with the EEC, the Forth and Clyde River Purification Boards,

the Departments of Forestry and Soil Science, University of Aberdeen, the Department of the Environment, the Central Electricity Generating Board, the DAFS Freshwater Fisheries Laboratory (Pitlochry), Imperial College, the Institute of Hydrology, the Royal Society and the North of Scotland College of Agriculture.

Members of staff are actively involved in relevant national/international working groups and committees. These include the Land Applications Panel for the European Space Agency Columbus programme (R.V. Birnie); the Land Applications Working Group of the National Remote Sensing Centre (G.G. Wright); the Mires Research Group and Meetings Committee of the British Ecological Society (P.D. Hulme); the Technical Group Contact for Project CPC-10 under the International Energy Agency's Bioenergy Implementation Agreement (M.F. Proe).

During the year there have been several staff changes. Sincere good wishes are extended to Miss Charlotte Flower, whose PhD research programme was completed in February 1986, to Mrs Karen Inglis and Miss Audrey M. Largue who resigned in March and May respectively, and to Mr R.A. Robertson O.B.E., Head of the Department, who retired in September 1986 after 35 years with the Macaulay Institute. A tribute to him appears elsewhere in this Report. A warm welcome is given to Mr Tom Gilmour, who joined the Remote Sensing Unit from the Department of Statistics in February 1986, to Miss Audrey H. Finnie who joined the Department in June, and to Miss Tricia M. Reid, who joined the Department from Spectrochemistry in August.

Terrain Resource Survey and Monitoring Operations

Peat Survey and Evaluation

Peat resource surveys have been carried out to determine the quantity and quality of peat available for production at a number of widely distributed sites. Most surveys were based on a grid established using a Wild T1 theodolite and DI4 electronic distance measuring equipment and site plans showing surface heights and peat depths were generated on a Wild TA plotter. At each site cores were extracted to determine the overall peat stratigraphy and reserves. The cores were also sampled for analysis in order to determine the utilization potential of the peat.

Topographical and stratigraphical surveys were conducted at three sites south of Edinburgh to assess their reserves of horticultural peat and level of sustainable production[1]. Dale Moss, a fuel peat production site in Caithness, topographically surveyed in 1985, was further sampled for peat quality assessment. A reconnaissance survey was undertaken around Highgreen in the Kielder area of Northumberland where the distribution and general characteristics of the deep peat were investigated[2]. At the request of the Scottish Development Department a survey of the Castlehill area of the Island of Islay has been carried out[3] to locate a suitable supply of peat for Scottish Malt Distillers as an alternative to developing Duich Moss. During the course of the survey the extent, quality and availability of peat suitable for machine cutting were investigated.

Surveys continue to be undertaken to provide information on peat resources and peat soils for inclusion in Memoirs of the Soil Survey of Scotland[4,5]. The inter-relationship of features such as peat type, vegetation, land use and horizon development is investigated. During the past year the survey and analysis of peat within the area of the Glasgow soil map was completed, surveys within central and north-eastern areas of the country progressed and a survey was started on the Island of Mull.

A detailed stratigraphical investigation of Ellergower Moss, a bog adjacent to the Silver Flowe National Nature Reserve in the Galloway Hills, was completed. The investigation is part of a collaborative study, with Prof. R.S. Clymo of Queen Mary College, University of London, on the stratigraphical development and ecology of the Moss.

A survey of the peatlands of the Shetland Islands is nearing completion. Ten peatland categories were identified on the basis of their vegetational, land use, topographical and hydrological characteristics and their distribution mapped on a base derived from a geometrically corrected Landsat image[6]. Many of the boundaries separating peat from the mineral and organo-mineral soils previously mapped by the Department of Soil Survey during their 1:250,000 scale survey of Scotland, were utilized.

For each mapped category, detailed vegetational recording was undertaken, land-use practices were investigated and the peat soils were described and sampled for analysis. In addition, selected deposits have been surveyed and sampled and an assessment made of their peat reserves and peat quality. A report to accompany the map, giving an account of these investigations is being prepared.

The Shetland Islands peatland map is the first to be produced entirely by digital methods. In this way the time-consuming and expensive draughting procedures associated with conventional published maps have been avoided, the entire compilation procedure being achieved by combining various map files within the computer and adding relevant information and text via the GEMS image processing system. Final map printing was achieved using a high quality colour inkjet plotter driven by the appropriate computer files for the three colour separations. This method of map compilation has several advantages when compared to conventional map production, the main ones being speed, ease of editing, low cost and flexibility. Because the map is essentially a series of computer files, these can be recombined in different ways to produce alternative outputs. It is therefore possible to produce one-off map products without incurring high production costs. It is intended to handle all future peatland survey information in this manner. 2035, 2036.

Palaeobotanical investigations

The results of collaborative work with the Central Excavation Unit of the Scottish Development Department at Strathallan, Perthshire await publication[7] (see Annual Report No. 55, p.57).

Studies designed to elucidate the processes of peat formation and development are continuing[8]. Since stratigraphical analysis and

interpretation of the botanical origin of peat features in many peat surveys, a palaeobotanical study with the objectives of i) investigating peat initiation and its successional development and ii) providing information to assist determinations of the botanical origin of peat, is in progress. Sites in the northern coastal area of Finland were selected for study. Here the land is rapidly rising from the sea (9mm each year) and in consequence there is a series of peat areas of differing ages at different stages of development. In this area hydrological and soil conditions ensure that peatland developmental stages that would span several hundred or even thousands of years in Scotland, are telescoped into a few centuries. Sites selected for study have been above the sea for no more than 500 years. Because of the short time span it is possible to determine the vegetational changes of the area on and around the peat deposits and, with the aid of this information, to investigate the relationship between the present botanical composition of the peat and its botanical origin.

Bracken Survey

The bracken survey of Scotland on behalf of DAFS continues along the lines previously reported[9]. One test site, at Glen Saugh, was resurveyed this year. Although no definite conclusions can be drawn from only two consecutive years' observations, there was evidence of change. Drawing out perpendicular lines from the previously defined boundary, and measuring from the intersection on the newly surveyed frontal position, reveals advances along bracken fronts in heather environs of up to 3 metres. Very little of the bracken/heather margin shows a bracken retreat.

The bracken/grassland margins behaved in a more stable manner. Advances there were restricted to a metre, with some retreating of up to a metre also evident. The increase in bracken cover, in a grassland environment, tended to be on the shallower slopes and deeper soils, compared to the little change observed on steeper slopes, shallow soils, with only diffuse bracken cover. A similar pattern emerged from a much more restricted check on the change in bracken front positions at Poltalloch in Argyll.

Regional bracken infestation has been recorded in two areas, Argyll and Angus (Kincardine and Deeside). The presence of bracken was recorded as a percentage of rough grazing in 1km grid squares. There were two objectives behind this. One was to gather further ground truth data for satellite based estimation of bracken cover. The second objective was to use the field observations as a measure against which the probability of bracken presence could be tested.

Information relating to land use, soil type, altitude, slope and aspect is also being compiled. This can then be used to test the sensitivity of bracken occurrence in relation to each of these variables. The results of this analysis will be used in combination with satellite imagery, to highlight areas of most severe bracken infestation.

Snow Surveys

The results of the programme to investigate the use of Landsat MSS imagery in assessment of regional snow conditions in the Scottish mountains have now been published[10]. 2034

The contract with the University of Aberdeen to investigate the reflectance characteristics of snow at mm wavelengths is ongoing. A third field season was successfully completed at the field site in the Bavarian Alps during February-March 1986. Measurements of snow-cover properties were made in support of 80-93 GHz radar trials. Macrophotography was used to record changes in snow crystal size and shape, and snow roughness. Snow surface wetness was estimated by combining surface density information with measures of the dielectric constant obtained using a University of Innsbruck instrument. Conductivity and pH of melted snow were measured in the field. Snow porosity was calculated from the density and snow wetness data. The possible dependence of 93GHz backscatter on variations in surface snow properties was investigated by multiple regression analysis. The results of this work were presented at the Snow Symposium VI in New Hampshire[11]. The next phase of the project will be concerned with establishing the spatial and temporal frequency of dry and wet snow from a combination of remotely sensed data and meteorological records. 2034

Aerial Surveys

Only limited aerial survey work was done in 1986, primarily to provide photography of proposed and existing peatland development sites in the Midland Valley. Considerable development work has been done, however, on the aircraft camera rig which has been adapted to allow two-man operation and now incorporates a video camera facility. The latter provides a means of improving the accuracy of aircraft tracking over photographic targets and also provides an inexpensive method of obtaining ground imagery. The possibilities of using aerial video photography as an alternative to conventional methods are currently being explored. Preliminary results, where video frames have been captured and subsequently manipulated within the GEMS image processing system, have been very promising, and indicate the potential of video photography as a reconnaissance technique.

Regional Crop Investigations

Regional crop survey work has continued along the lines previously reported. The major effort has been towards the production of a regional data base to enable examination of the potato crop distribution in relation to drought-risk. This work is collaborative with the Scottish Crop Research Institute (SCRI) and is based on their need to establish what proportion of the potato crop is being grown in drought-prone areas. This should, in theory, help explain the commonly encountered shortfall between actual and predicted yields of the potato crop in eastern Scotland.

To enable the necessary regional analysis to be performed a small scale geographic data base has been assembled. This includes the following digital map information:

(i) Agroclimatic Areas (Met. Office data, 1:625,000)
(ii) Urban Areas (O.S. 1:250,000 Routemaster)
(iii) Region and District boundaries (O.S. 1:250,000 Adin.)
*(iv) Woodland and Moorland
(classified from LANDSAT 221/20, 30/5/82 image)
(v) Potential Water Deficit
(Macaulay Institute — Soil Survey Climatic maps)
(vi) Rainfall (Met. Office, 1:625,000 data)
*(vii) Soil (Soil Survey of Scotland, 1:250,000 data)
(viii) Altitude (O.S. 1:625,000 digital data)
*(ix) LANDSAT potato fields, 1982.

Vector and raster digitised data are available for O.S. 1:250,000 Sheet 5 area (Eastern Scotland) for all maps except these marked *. For these, data are available for only the 1024 × 1024 pixel test area (including Kincardine and Deeside).

SCRI has identified soil type and potential water deficit as the two most important environmental factors affecting yield. Accordingly, it was the objective of this study to determine where potatoes were growing in areas with high potential water deficit and on drought susceptible soils. The LANDSAT classification provided the location of all potato fields (greater than 2ha) within Kincardine and Deeside and, by interacting this with the map data, it was possible to provide the statistical data on crops in drought prone areas. As the data were accessed via the GEMS image processing system, the locations as well as area statistics could be provided so that regional distribution could be analysed.

Using the soil, potential water deficit (PWD) and potato field classification, the area of potatoes grown on every soil unit within each PWD area was classified. The area of each soil unit was also classified and the percentage of that area planted to potatoes in each PWD calculated. Only 19 of the 27 soil units within Kincardine and Deeside were found to be supporting a potato crop. It was found that 200ha (9.4 per cent of the total crop) of potatoes had a high drought risk. Of this total some 113ha were growing on two soils, 63ha on Stonehaven freely drained soil (with a PWD > 75mm) and 70ha m Forfar freely drained soil (PWD 50-75mm). The results of this work are currently being prepared for publication. 2033, 2034

Crop Reflectance Studies

Winter Oilseed Rape (WOSR)

From autumn 1985 until spring 1986 a programme of crop cover and crop reflectance measurements was undertaken in collaboration with the North of Scotland College of Agriculture on a late sown winter oilseed rape crop. The trial was designed to investigate the growth effects of different applications of metazachlor herbicide. The object of this study was to

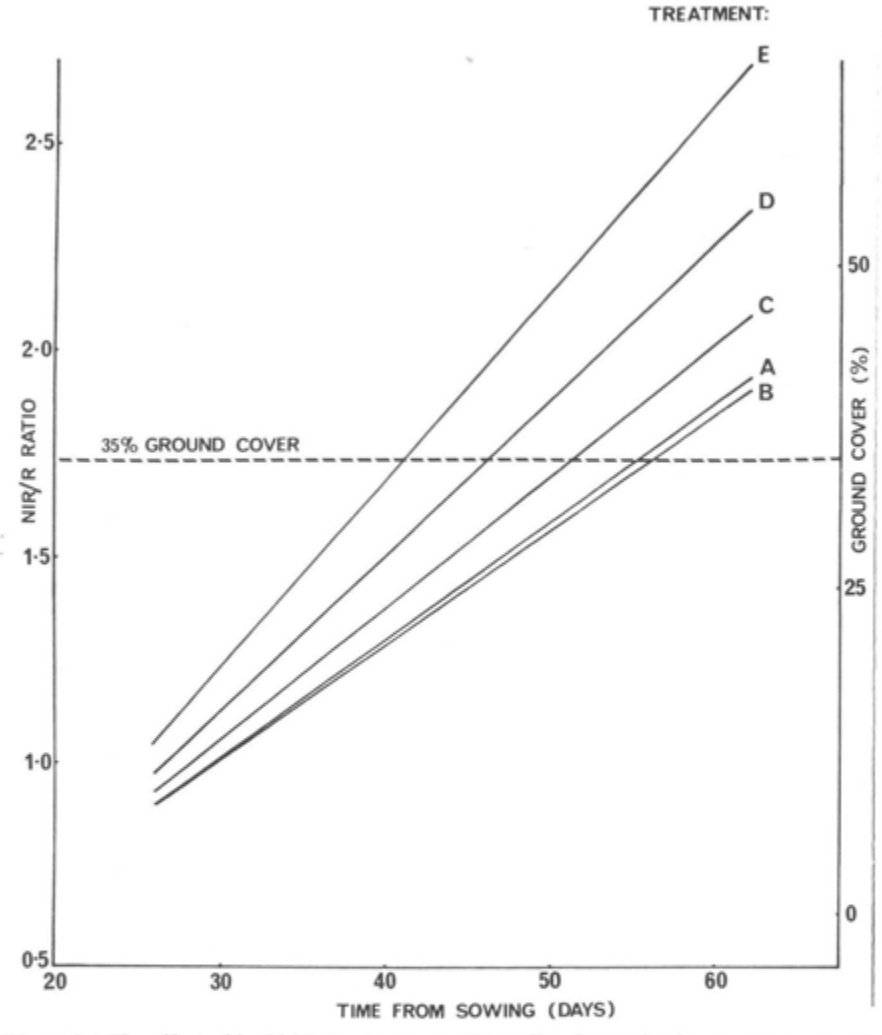


Figure 2.1 The effect of herbicide treatment on winter oilseed rape development as measured by visible/near-infrared radiometry. Results show clearly that pre-emergent spraying (treatments A and B) cause greatest retardation on rate of ground coverage and thus increase erosion susceptibility. (Treatments were as follows: A — ½ pre-emergence, ½ post-emergence; B — full pre-emergence; C — full post-emergence; D — post-emergence; E — no application).

establish the relationship between ground cover (GC) and the NIR/R (R) ratio for WOSR. This relationship was then used to monitor the growth rate for pre- and post-emergence herbicide spraying. A comparison of the radiometric data and GC measurements produced photographically for the autumn growth stage indicated GC and R were highly correlated up to canopy closure: Percent Ground Cover (GC) = (NIR/R) — 0.631/0.0313.

The correlation coefficient (R) was 0.974 ($P < 0.001$, 28 degrees of freedom). Spring GC measurements were made using this relationship.

Plant counts made from photographs taken shortly after emergence indicated a severe effect on germination rates if pre-emergence spraying was undertaken. Full dose rate (2.5kg/ha) pre-emergence spraying resulted in an autumn plant density of 113 plants per square metre, whereas a plant density of 139 and 148 was recorded for full rate (2.5kg/ha) post-emergence and control treatments.

The increase in percentage ground cover per day per plant was assessed using plant counts and radiance values. Growth rates between herbicide treatments showed little variation, but were approximately half those achieved in the untreated plots.

This retardation of germination and growth rate may have a serious environmental consequence. If the crop is late sown and growing on soil with a high erosion risk, the result of herbicide spraying particularly will be a delay in ground cover establishment and a consequent increase in erosion liability (Fig. 2.1). This work has been submitted for publication[12].

2032, 2034, 2071

Potatoes

The 1985 measurement programme provided sufficient data to test the hypothesis that up to canopy closure the near infrared/red (NIR/R) ratio obtained for field radiometric measurements is highly correlated with ground cover. A linear correlation coefficient of 0.99 was computed for an equation of the form: $GC = -17.55 + 23.77 \times NIR/R$. When analysed separately no significant difference was found between the slopes and intercepts of the equations for the individual nitrogen treatments suggesting that the relationship between the reflectance ratio and GC is independent of applied fertilizer level, up to canopy closure. These results have been prepared for publication[13]. During the 1986 growing season a daily programme of radiometric measurements has been undertaken over a nitrogen-fertilization trial conducted by the Department of Soil Fertility within the Institute's grounds. The objective of this work was, through increasing the measurement frequency, to confirm the presence of apparent spectral features, such as the pronounced dip in the NIR/R ratio after canopy closure, and secondly to test whether extreme forms of nitrogen stress do influence the relationship between the NIR/R ratio and ground cover. These results are now being analysed. 2032, 2071, 7047

Winter Barley

The previous work on wind turbulence effects on radiation measurements has now been published[14].

Detailed analysis of the crop reflectance data has shown the potential for using the non-destructive radiometer results at different crop stages. In the autumn growth period prior to winter senescence there is a good correlation between Near Infrared/Red values (NIR/R) and live leaf area, correlation coefficient 0.99 $P < 0.001$. There is also a strong relationship at this time for NIR/R and dry matter (live and dead leaves), correlation coefficient 0.99, $P < 0.001$.

A relationship was established in 1985 (Annual Report No. 55) between grain yield and the mean NIR/R value between spring regrowth and grain ripening (coefficient of correlation 0.83, $P < 0.001$). This analysis used the data from 80 different treatments (all replicated). This analysis correctly identified the performance sequence of over 80 per cent of these treatments. It is intended to use the T-sum (accumulated mean daily temperature) values corresponding to the sample days to obtain a better grain prediction model using NIR/R values. 2032, 2071

Soil Reflectance Studies

Following on from the laboratory reflectance study on the SPOT simulation soils[15] the potential for using discrete wavebands to quantify some soil properties is being investigated. A scanning radiometer is being built which will give a greater choice of discrete wavebands for this study.

Using a three band radiometer developed at Aberdeen University Department of Soil Science, reflectance values (Green, Red and Infrared) have been obtained for 58 soils. These soils have a greater range of textures and organic matter than the soils included in the SPOT simulation study. There are now soil reflectance data for 108 soil samples.

Preliminary analysis of reflectance values from the 58 new soils shows they are highly correlated with the laboratory results for organic carbon and loss on ignition. Laboratory moisture contents are often less than 2 per cent and do not appear to have a significant influence on the reflectance properties. The relationship between organic matter content and reflectance is poorer if the textural classes are considered together. Further investigation into the soil characteristics and reflectance interrelationships continues. 2032, 2071

Automated Photogrammetry, Image Processing and Digital Mapping

Work has continued on the development of a methodology for the segmentation and classification of remotely sensed imagery. The first step in the process, to split the image into the basic spectral classes, was initially attempted using supervised per point classifiers. It was observed that the classification error rate could be decreased by smoothing the image with an averaging filter before classification. A technique has been developed which gives guidance to the user as to the size of neighbourhood required for averaging over so as to ensure the error rate is no more than a specified level. The technique uses the distributional properties of the population means and the correlation between neighbouring pixels within each class. The method has proved effective, in particular where the classes are of a non-cellular structure.

The aim of this segmentation is to be left only with the agricultural areas within which crop information is to be extracted. Tests have been made on high resolution imagery of agricultural areas to ascertain whether or not it is possible to segment the image on within-field statistics. This has proved advantageous whilst working on small areas and has highlighted the possibilities of using texture measures to detect irregular crop development.

Links have been made with the Department of Statistics at Leeds University, with the possibility of collaboration in the future on image segmentation problems. 2033, 2034

During 1986 a video digitising system and inkjet printer have been added to the GEMS image processing system. This along with the implementation of an update of the GEMSTONE software (to version 1.2) has provided the Remote Sensing Unit with facilities not previously available. The video input allows images to be captured directly into GEMS, via a video camera, thus providing a fast economical method of digitising. It has proved useful for work on aerial photographs, but is unsatisfactory at present for work on digitising line maps. The inkjet printer facilitates screen dumps from the GEMS monitor to be taken and despite the disparity in colour definition has proved to be a useful facility.

The GEMS system has been increasingly used as a medium for the compilation and manipulation of map data. The seed-fill facility within the new version of GEMSTONE has proved especially useful in this application.

Software has been written to control the second Ferranti digitising system, acquired during 1985, and this is now fully operational. 2033

A soil map was produced for a project undertaken by the Department of Soil Survey for the Forestry Commission. The map was photogrammetrically plotted from a strip of five aerial photographs onto which soil class boundaries had been annotated. The 200 metre and 500 metre contours were also plotted, the latter demarking the upslope boundary of the area of interest.

This base map was then digitized, and all soil class polygons smaller than one hectare were excluded. A plot was then produced of the compiled map and passed to the Department of Soil Survey for further analysis.

2033, 2034

Nutrient Cycling in Forests

Investigations into the use of mixed species to improve the nitrogen nutrition of Sitka spruce are now complete and a report has been submitted to the Commission of the European Community who part funded the project[16]. The objectives of this work were:

1) to elucidate the processes that enable nitrogen and other nutrients to cycle more rapidly in mixed spruce-larch and spruce-pine crops than in pure spruce crops.
2) to suggest means by which such knowledge might be used to develop low input but high productivity silvicultural systems.
3) to identify the disturbance to nutrient cycles and tree growth that are ascribable to acid rain, by comparing results from widely separated sites.

Collaborating bodies included the Forestry Commission, the University Departments of Forestry (Aberdeen) and Forestry and Natural Resources

(Edinburgh) together with the Irish Forest and Wildlife Service. The results obtained indicate that no single factor has been identified as being responsible for the improved growth of spruce when planted in mixture. A number of factors may, however, act in concert and these may include:

1) Suppression of heather by nurse species. Heather has long been known to be antagonistic toward spruce development and this was illustrated in a glass-house trial using soil from Culloden forest during which a significant depression in spruce root development was observed (36.5g dry weight per plant in the absence of heather as opposed to 15.3g when heather was present). Although likely to be important at Culloden there was comparatively little heather present at Inchnacardoch and the mixture effect is known to occur on sites where heather is virtually absent.

TABLE 2.1 Comparisons of weights of foliage by age classes on pine and spruce in mixed plantations

	Foliage Biomass (t ha^{-1})		
CULLODEN	1st year	2nd year	[>] 2nd year
Sitka spruce	2.1	2.4	3.7
Scots pine	2.3	1.9	0.3
INCHNACARDOCH			
Sitka spruce	4.0	4.2	5.0
Lodgepole pine	3.0	3.0	2.8

2) Increased foliage retention in spruce compared to nurse species. Although Sitka spruce produces new foliage at approximately the same rate as the nurse species, foliage retention is longer and, therefore, significant quantities of nutrients may be retained within the developing canopy prior to its full development (Table 2.1). Thus when planted in mixture the high demand made by the spruce may be diluted on a per hectare basis to enable the spruce to make satisfactory growth[17] Calculations suggest, however, that such contributions are small and unlikely to provide a complete explanation.
3) Enhanced cycling of nutrients in the mixed compared to the pure plots. Nutrients were found to be cycling more rapidly in the mixed plots compared to the pure in terms of litterfall, throughfall and stemflow. These, however, appeared to be a consequence rather than a cause of the improved growth.
4) Increased rooting depth of spruce. Although perhaps important in the establishment and stability of spruce plantations this effect is unlikely to have a significant impact on nutrition.

In addition to the effects outlined above further factors, including the role of mycorrhiza, may be important in conferring advantages in mixed species.

2054, 2055, 2056, 2807

Balquhidder Catchment Studies

Work has continued on the results from the catchment studies at Kirkton and Monachyle glens, near Balquhidder, which were set up to assess the

effects of afforestation and deforestation on water quality and quantity. Statistical analysis of the field data and chemical analysis of the samples from the whole tree harvesting at Kirkton were carried out to determine the amounts of nutrients in the standing crop. The Kirkton catchment, which is 60% forested with a number of species including Sitka spruce, Norway spruce, Scots pine and Japanese larch, is being progressively clear-felled, whereas site preparation and planting have started at Monachyle.

Weekly samples have been collected from the main outflow streams at both sites for routine chemical analysis. Filtered particulate material from selected stream samples have also been examined using XRF and XRD. Results indicate these stream deposits comprise mica and chlorite with lesser amounts of felspar and amphibole derived from local soils.

The harmonised water monitoring scheme, which was set up by the Balquhidder consortium to provide quality control on methods of chemical analysis has continued with a series of precision, followed by bias, tests on some of the original determinands.

This scheme has also proved useful in the analysis of samples provided by the Surface Water Acidification Project (SWAP) which involves some of the participating laboratories 2054

Nutrient Cycling Studies

Processing the large amounts of data produced from the nutrient cycling experiments in both Sitka spruce[17,18] and birch has continued. 2054

The computer simulation model, FENDS, developed to examine relationships between growth and nitrogen dynamics in stands of Corsican pine has now been used to forecast the likely impact of whole-tree harvesting for this species[19]. This work was carried out as part of an international collaborative project implemented through the International Energy Agency and designed to examine the nutritional consequences of intensive forest harvesting on site productivity. Preliminary investigations using FENDS suggested that heavy inputs of nitrogen fertiliser would eventually be required to sustain a system of whole-tree harvesting on many sites. Such fertiliser applications may, in some cases, be used more efficiently to increase yields of conventionally harvested timber as opposed to supporting whole-tree systems on sites where nitrogen availability may be a serious limitation to growth. 2054, 2056

Information on processes controlling growth and nutrient cycling in young plantations is limited. Recent experience in the Forestry Commission suggests that nutrient deficiency problems will frequently be reduced in second rotation stands. To examine some of the factors controlling nutrient availability and tree growth on restocked sites a new experiment has been superimposed upon a recently clearfelled fertiliser experiment laid down at Culbin Forest, Moray in 1964 in collaboration with the Forestry Commission and for which detailed historical records are available. Two treatments have been selected for intensive studies, the control which received no nitrogen during the first rotation and the heaviest fertilised plots on which 1512kg N ha^{-1} was applied. Each system was sampled in terms of

biomass and nutrient distribution prior to clearfelling and future studies will include the breakdown of harvesting residues, release and uptake of nutrients together with inputs to and losses from each system. The overall objective of this work is to construct nutrient budgets and water balances for restocked areas of Corsican pine and to assess the impact of first rotation fertiliser applications upon the establishment of a second rotation. 2054, 2056.

Forest Nursery Nutrition

During the year under review the Nursery Advisory Service received 130 soil samples for analysis of which over one third came from the private sector. This figure compares with an annual average of approximately 200 samples during the previous three years. The service has also analysed 48 samples of foliage of which 30 originated from the sewage sludge experiments at Angus and Ardross Forests referred to in last year's report. The Forestry Commission also requested the chemical analysis of irrigation water from a number of nurseries all of which were found to have suitable supplies. Throughout the year a small number of persistent problems have been observed in several nurseries and analyses have indicated possible trace element deficiencies with copper or boron being most likely. No conclusive evidence was found, however, and a close watch will be kept during the forthcoming season. Discussions on the future role of the Advisory Service took place at the annual meeting of Forestry Commission nursery managers at which representatives from the private sector were present. There was general agreement that the service could be improved by the development of a central database at the Institute containing records of soil analyses, fertiliser applications, organic amendments, plant performance and meteorological data. In addition, the wider use of foliage analyses may help to ensure the optimum use of fertilisers on specific nursery sections and to provide additional data on micro-nutrient levels. Discussions continue on how such a programme could be implemented in future years. 2056

Acid Rain Studies

The 3 year project sponsored by the Department of the Environment to study changes in rain and soil water chemistry on passing through forested and unforested sites at Loch Fleet (Galloway) and Fetteresso (Aberdeenshire), has entered its final year. The objective of this study is to assess the effect that vegetation and soils have in modifying incoming rainfall acidity and to investigate the processes involved. The effect of applying supplementary base cations to the forest is also being assessed as a possible means of ameliorating incoming acidity.

Rainwater, throughfall, stemflow, litter water, soil water throughflow and stream water samples have been collected at fortnightly intervals for the two years 1985 and 1986. In addition to these baseline data, several storm events have been intensively sampled during 1986 to monitor changes in rainwater, throughfall, soil and stream water chemistries. Trees were found to acidify incoming rainfall further for 11 months of the year at Loch Fleet

(Sitka spruce and Lodgepole pine P63) and for 6 months at Fetteresso (Lodgepole pine P63), the pH generally decreasing in the order rainfall > throughfall > stemflow > litter water[20]. The forest canopy and forest floor at Loch Fleet showed little ability to neutralise incoming rainfall acidity due to the poor nutrient status of the site. An important source of acidification resulted from $NH_4^+ \rightleftharpoons H^+$ exchange in the tree canopy of nitrogen deficient stands, which was shown to be reversible by the application of urea to the forest floor. The better nutrient status at Fetteresso was reflected in the forest's ability to neutralise rainwater acidity during the summer months when cation exchange in the tree crowns is most marked.

The study has also highlighted the importance of soil hydrology in controlling the passage of vegetation and rainfall-derived acidity into streams[21]. At Loch Fleet the predominantly saturated nature of the thin moorland soils resulted in surface runoff occurring immediately after the onset of rainfall. Upward of 90% of the total downslope flow was routed through the soil surface (pH 4.0 to 4.3). The surface flow from the forest was more acidic (pH 3.6 to 4.0). At Fetteresso the steep valley slopes characteristic of the upper reaches of streams in that area have been shown to produce significant acid episodes during storm and snow melt events. During such events the bulk of downslope flow is routed through the soil surface, resulting in a rapid drop in streamwater pH (eg pH 6.0 to 4.3). The presence of a forest cover greatly modified the soil hydrology giving a marked reduction in the volume of surface flow. 2066, 2073.

Surface Water Acidification Programme (SWAP)

The Surface Water Acidification Programme is a multi-disciplinary approach to study the mechanisms responsible, and the processes involved, in the acidification of surface waters. Apart from the Macaulay Institute's Departments of Peat and Forest Soils, Soil Organic Chemistry, Mineral Soils and Spectrochemistry, the Programme involves other institutes, including the DAFS Freshwater Fisheries Laboratory (Pitlochry), Imperial College (London) and the ITE Institute of Hydrology (Wallingford).

The objectives of this work are 1) to elucidate the processes by which soils and vegetation modify the chemistry of surface waters and 2) to identify factors which contribute to the passage of acidity into streams during prolonged periods of heavy rainfall or snowmelt.

Three sites in the Allt-a'-Mharcaidh catchment of the Cairngorms and two in the Loch Ard area, west of Stirling, have now been fully instrumented for the collection of rainfall, mist interception, occult deposition, vegetation and litter throughflow, soil solution from selected horizons, and stream waters. Sampling has been carried out at two weekly intervals at the Loch Ard catchments since December 1985, and at two sites in the Allt-a'-Mharcaidh since March 1986. Because of prolonged snow cover, the alpine podzol site at Allt-a'-Mharcaidh could not be instrumented until May 1986. The equipment at all of the sites appears to be operating satisfactorily. Samples collected from the Department of Peat and Forest Soil's sites are subsequently passed to the Department of Soil

Organic Chemistry for additional analyses of dissolved organic carbon, and to the Department of Spectrochemistry for determination of aluminium speciation and trace metal analysis. Each site has been instrumented to collect hourly composite samples, from all parts of the system, for a period of 24 hours during selected storm events. An intensive study of the spring snowmelt events at Allt-a'-Mharcaidh in February/March 1987 is planned in a collaborative project with the Institute of Hydrology, who have identified discrete acidifying flushes in the main stream during snowmelt events in 1986. All sites have been instrumented by the Civil Engineering Department of Imperial College with a tensiometer network designed to measure soil matric potentials, flow pathways, and local hydrology of the soil types under study. Data loggers connected to the tipping buckets used by the Department of Peat and Forest Soils have also supplied information on the temporal and spatial hydrology of the soils during periods of unsaturated and saturated flow[22].

The two separate regions that have been selected for the SWAP investigations in Scotland are subject to either heavy (Loch Ard catchments) or moderate (Allt-a'-Mharcaidh) pollution loadings, and there was a demand for information from a natural system in a pristine area. The management committee of SWAP identified a site at Høylandet, north of Trondheim in Norway as suitable, and it was thought that Macaulay involvement at this site would complement research carried out by a number of Norwegian Institutes. In September 1986, this site, which is natural spruce forest on iron podzolic soils, was fully instrumented by members of the Department using redesigned equipment similar to that used in the Scottish studies. Samples are returned to the Institute for analysis. It is hoped that a detailed investigation of the rapid late spring snowmelt can be undertaken by institute staff in 1987. Collection of baseline data will continue throughout 1987 for all six sites (Objective (1)), and an increased research effort will be directed towards identifying these factors which contribute to the passage of acidity into streams during rain and snowmelt events (Objective (2)).

Collaborative work with the Institute of Hydrology and Imperial College will continue with particular attention paid to flow rates and pathways through each system under study. More detailed research into the role of vegetation in acidification processes will also be undertaken along with a programme of routine SO_2 measurement (dry deposition).

Nutrient availability in highly organic soils

The investigation into nitrogen availability and uptake on poorly drained reseeded peat at Forsinard, Sutherland has been continued for a second growing season. Experimental plots, protected from grazing, were given 60kg P ha^{-1} as granular superphosphate and 60kg K ha^{-1} as potassium chloride in April and June. Half of the plots were given 112.5kg N ha^{-1} as ammonium nitrate in April and again in June after the first harvest of grass which was also harvested in August and October. Peat cores from PK and NPK treatments were sampled monthly between March and October and analyzed for mineral nitrogen, extractable phosphate and acidity. In collaboration with the Department of Microbiology, rates of potential

denitrification were also measured and these showed a marked seasonal pattern that appeared independent of moisture conditions in the peat. The potential for denitrification was greatest during March and April when fertilizer-N is usually applied. These results together with counts of the numbers of denitrifying bacteria were presented at "Microbe 86", the XIV International Congress of Microbiology. Applications of urea have been tested as an alternative to ammonium nitrate and so far dry matter yields have been similar with both forms of nitrogen under field and glasshouse conditions. Ammonium concentrations have also been monitored in fertilized and untreated peat and it has been observed that these were high at the beginning of each growing season prior to fertilizer application, reaching 40kg N ha^{-1} in March and April. Furthermore, incubating cores of peat under field conditions has shown that in the absence of plant uptake ammonium nitrogen is transformed and immobilized in the peat. The occurrence of both denitrification and immobilization of N in this very wet deep peat would account for the poor response and low recovery of fertilizer-N in the grass. More recently work has been directed towards identifying the fate of the immobilized N. 2055, 6027

In collaboration with the Department of Soil Organic Chemistry interactions between peat and ^{14}C-labelled substrates, such as glycine and glucose, have been studied. The location of newly synthesized carbohydrates was determined by fractionating peat on the basis of particle size using a wet sieving technique. An account of this work has been submitted for publication[23]. Abiotic interactions between ^{15}N labelled glycine and peat sterilized by autoclaving and γ-irradiation have been investigated in collaboration with the Department of Soil Organic Chemistry, the Chemistry and Biology Research Institute, Agriculture Canada, and the Division of Chemistry, National Research Council, Ottowa. Nuclear magnetic resonance (NMR) spectra for ^{15}N and ^{13}C atoms were obtained on particle size fractions separated from peat that had been incubated for 6 months with ^{15}N glycine. ^{15}N spectra corresponding to amines, secondary amide and pyrrole type nitrogen indicated the possible involvement of the Maillard reaction in the humification process[24]. 2055, 4020, 6027

The role of the microbial biomass in highly organic soils as a source of potentially available nitrogen and phosphorus has been studied in collaboration with the Department of Microbiology. A paper on the release of nitrogen and phosphorus from coniferous forest humus amended with glucose and cellulose and then fumigated with chloroform has now been published[25]. 2055, 6027

The final report of the EEC-funded project on nitrogen cycling in pure and mixed stands of Sitka spruce has been submitted[16]. As a part of this study, the concentrations of different forms of nitrogen in humus (L + F + H) and soil beneath pure Sitka spruce (SS) and mixed Sitka spruce + Scots pine (SS + SP) stands were determined monthly at Culloden forest, Inverness-shire. The trees in the two treatments contrasted greatly in their N status indicating greater N availability beneath SS + SP than SS. The differences between the stands were reflected in the levels of exchangeable

ammonium N and the amounts of nitrogen mineralized under both field and laboratory conditions which on occasions were significantly ($P < 0.05$) greater in humus beneath SS + SP than SS. The sources of the readily mineralized nitrogen and the mechanisms that stimulated the improved growth of the mixed species were not apparent. Litter leaching experiments with pure SS, SP and a 1:1 mixture were conducted to test the hypothesis that decomposition was accelerated in mixed litters. In two joint experiments with the Department of Microbiology SS litter released more soluble nitrogen (NH_4 + NO_3 + Organic-N) than SP, but a positive interaction in terms of N release occurred only once when enchytraeid worms were present. A second experiment without worms failed to give a positive interaction in soluble N, but estimates of microbial biomass N indicated a positive interaction. On both occasions microbial respiration measured as evolved CO_2 was greater in SS than in SP litters and there was a positive interaction in SS + SP. The presence of the enchytraeid worms could have affected the results and their role in nutrient release from decomposing litters has been studied in a further experiment the results of which are still being analyzed. 2055, 2087, 6027, 6087

References

1. Survey and assessment of peat resources at Springfield, Whim and Auchencorth Mosses, near Penicuik, Midlothian. Department of Peat and Forest Soils. A report for Scottish Agricultural Industries. 1986.
2. An investigation of the peat deposits of Highgreen Estate, Northumberland. By P.D. Hulme and A.W. Blyth. A report for Highgreen Estate. 1986.
3. The peat resources of Castlehill, Isle of Islay. Department of Peat and Forest Soils. A report for the Scottish Development Department. 1986.
4. Peat. By P.D. Hulme and R.A. Robertson. To appear in *Memoirs of the Soil Survey of Scotland* : *Soils of Fife and Kinross*. By D. Laing and J.S. Robertson. Aberdeen. Macaulay Institute for Soil Research.
5. Peat. By P.D. Hulme and R.A. Robertson. To appear in *Memoirs of the Soil Survey of Scotland* : *Soils of Orkney*. By F.T. Dry. Aberdeen. Macaulay Institute for Soil Research.
6. The Peatlands of the Shetlands Islands. Aberdeen. Macaulay Institute for Soil Research. 1986.
7. Pollen analysis of a radiocarbon dated core from North Mains, Strathallan, Perthshire. By P.D. Hulme and J. Shirriffs. To appear in *Proc. Soc. Antiqu. Scot.* **115**.
8. The origin and development of wet hollows and pools on Craigeazle Mire, south west Scotland. By P.D. Hulme. *International Peat Journal* **1**, 15-28. 1986.
9. The Bracken Problem in Scotland : A new assessment using remotely sensed data. By R.V. Birnie and D.R. Miller. *Proc. Int. Conf. "Bracken 85", Leeds*, 43-55, 1986.
10. Pixel-mixing effects and their significance to identifying snow conditions from LANDSAT MSS data. By R.V. Birnie. *Int. J. Remote Sensing*, 7(7), 845-853, 1986.

11. Millimetric Radar Backscatter Trials : Surface Snow Properties and their Relation to Backscatter. By L.D. Williams, D.E. Sugden and R.V. Birnie. *Proc. Snow Symposium VI, CRREL, Hanover, New Hampshire* (in press).
12. Herbicide treatment on winter oilseed rape and its implication to increasing soil erosion risk in marginal cropping areas of the United Kingdom. By G.G. Wright. *Soil and Land Use Management* (in press).
13. Estimation of Percentage Ground Cover in Potatoes by Optical Radiance Measurements. By R.V. Birnie, P. Millard, M.J. Adams and G.G. Wright. *Research and Development in Agriculture* (in press).
14. Some observations on the effect of wind turbulence on the near infrared/red ratio. By G.G. Wright. *Int. J. Remote Sensing*, **7**(1), 173-178, 1986.
15. Detection of surface soil variation using high resolution satellite data : results from the UK SPOT-simulation investigation. By G.G. Wright and R.V. Birnie. *Int. J. Remote Sensing*, **7**(6), 757-766, 1986.
16. Maintenance and enhancement of forest productivity through manipulation of the nitrogen cycle. By H.G. Miller, Clare E. Alexander, Jean Cooper, John Keenleyside, Helen McKay, J.D. Miller and B.L. Williams. Final report to the European Research and Development Programme, Wood as a renewable raw material, Contract No. BOS-093 UK. 1986.
17. Nutritional requirements of Sitka spruce. By H.G. Miller and J.D. Miller. *Proc. Roy. Soc., Edinburgh*, Series B. (in press).
18. Transformations in rainwater chemistry on passing through forested ecosystems. By H.G. Miller, J.D. Miller and Jean M. Cooper. *Proc. Brit. Ecol. Soc. Mtg., Bristol*, 171-180, 1985.
19. Predicting the effect of whole tree harvesting on long-term site productivity for stands of Corsican pine. By M.F. Proe. In Agren, G.I. (Ed.) Predicting consequences of intensive forest harvesting on long-term productivity. Swed. Univ. Agric. Sci. Dept. Ecology and Environmental Research Report No. 26, 117-129. 1986.
20. Changes in rainwater chemistry on passage through a forested ecosystem at Loch Fleet, Galloway. By A.F. Leech. In The Loch Fleet Project — a Report of the Pre-intervention Phase (1) 1984-1986. CEGB, Leatherhead, pp A4.1-4.8. 1986.
21. Changes in the chemistry of water passing over and through soils in forested and unforested sites at Loch Fleet, Galloway. By T.R. Nisbet. In The Loch Fleet Project — A Report of the Pre-intervention Phase (1) 1984-1986. CEGB, Leatherhead, pp A5.1-5.5. 1986.
22. The determination of hydrological flow paths and associated hydrochemistry in forested catchments. By H.S. Wheater, S.J. Langon, J.D. Miller and R.C. Ferrier. Submitted to IAHS, Vancouver, 1987.
23. Distribution of ^{14}C between particle size fractions and carbohydrates separated from a peat incubated with ^{14}C glycine. By B.L. Williams, M.V. Cheshire and G.P. Sparling. Submitted to the *Journal of Soil Science*.

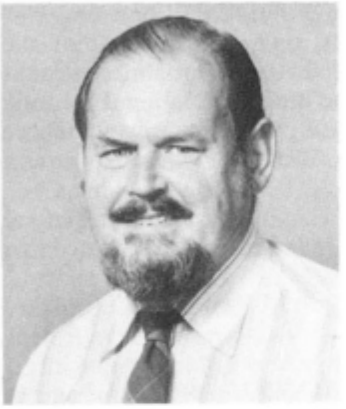
24. Fate of [^{15}N] glycine in peat as determined by ^{13}C and ^{15}N CP-MAS NMR spectroscopy. By Laure M. Benzing-Purdie, M.V. Cheshire, B.L. Williams, G.P. Sparling, C.I. Ratcliffe and J.A. Ripmeester. *Journal of Agricultural and Food Chemistry*, **34**, 170-176, 1986.
25. Microbial biomass in organic soils : estimation of biomass C, and effect of glucose or cellulose amendments on the amounts of N and P released by fumigation. By G.P. Sparling and B.L. Williams. *Soil Biology and Biochemistry*, **18**, 507-513, 1986.

Other publications

Production and Transfer of Subaerially Generated Rock Debris and Resulting Landforms on South Georgia : An Introductory Perspective. By J.E. Gordon and R.V. Birnie. *British Antarctic Survey Bulletin* (72), 25-46, 1986.

3. SPECTROCHEMISTRY

M.L. BERROW



The work of the Department of Spectrochemistry is primarily concerned with investigations of the form and distribution of chemical elements in soil/plant systems. These investigations have continued to embrace the themes of earlier years, but emphasis has recently been placed on computerisation and the development of automatic sample handling systems. The five main themes are (1) studies of the distribution of trace elements in soils, plants and biological materials, (2) the investigation of soil-plant trace element relationships in the field, (3) the elucidation of the structure, composition and forms of soil components, (4) the provision of an analytical service for trace and major elements to the Institute and to the North of Scotland College of Agriculture for their advisory service to farmers and (5) the development of spectrochemical methods to implement these programmes.

This year has seen the retirement of Dr. A.M. Ure as Head of the Department. A tribute to him and his work in the Department over a period of 38 years is given in the Introduction.

Attendance at national and international conferences and papers presented at them by departmental staff are detailed in Appendices II and III of this report. The Department has been represented on various national and international committees and working parties. These include DAFS Consultative Committee on Spectrochemical Work (T.S. West, Chairman; A.M. Ure, Technical Secretary; M.L. Berrow), IUPAC Commission V-4 on Spectrochemical Methods (A.M. Ure), FAO European Co-operative Network on Trace Elements (A.M. Ure), Department of the Environment, Standing Committee of Analysts (Main Committee, A.M. Ure; Working Group 4, M.L. Berrow, B.L. Sharp), MISR/COSAC Liaison Group (M.L. Berrow), MISR/COSAC Working Party on Advisory Soil Analysis and Interpretation (M.L. Berrow), the Association of Scottish Industrial Analysts (J.C. Burridge, Chairman) and the Royal Society of Chemistry — Analytical Editorial Board (A.M. Ure, B.L. Sharp) — Analytical Spectrometry Updates (B.L. Sharp, Chairman; A.M. Ure, Secretary; J.C. Burridge) — Editorial Board Journal of Analytical Atomic Spectrometry (A.M. Ure, B.L. Sharp) — Scottish Region Committee (M.J. Adams, Vice Chairman) — Agriculture Group, Industrial Division (A.M. Ure). A.M. Ure has also served as a member of the Analytical sub-committee of the British National Committee for Chemistry and B.L. Sharp on the Editorial Board of Spectrochimica Acta, Part B. M.L. Berrow served on the Technical Programme Committees of International Conferences on

Chemicals in the Environment (Lisbon) and Environmental Contamination (Amsterdam). B.A. Goodman has served as convenor of a working party of the International Humic Substances Society, on a MAFF sub-group on the speciation of trace elements in food and on an AFRS study group on the aetiology and control of nutritional disorders.

Four members of staff of the Department, one as a member of the Scientific Committee (B.L. Sharp), attended the joint International Conference of the RSC, Analytical Division/Biennial National Atomic Spectroscopy Symposium (SAC86/3rd BNASS) held at Bristol. Three contributions were presented at this meeting, details of which appear in later sections.

Three book chapters have been produced during the past year on general topics of relevance to soils[1–3] and the contents of these are also reported in a later section.

Trace Elements in Soils, Plants and Biological Materials

Soils and Soil Parent Materials

Analyses of 68 profiles from the Ardnamurchan-Morvern area (Sheet 52) for total and extractable trace elements have been completed. Analyses of samples from 30 profiles representing 21 soil associations which cover small but significant areas in other parts of Scotland and for which little or no trace element information is available have also been completed. Trace element data have now been obtained for all the main soil associations mapped throughout Scotland and can be used to prepare soil trace element maps. Such maps based upon the total cobalt, copper or nickel contents in soil profile B-horizons of the different soil associations have been produced in collaboration with the Scottish Soil Survey. The maps broadly indicate areas where soils are inherently low, medium or high in these three elements and give a preliminary indication of the likelihood of trace element related disorders arising. These data formed part of the Institute's contribution to the BBC's Domesday Project. A map based on the amounts of extractable cobalt in topsoils of the different soil series in the Aberdeen area has also been produced on a scale of 1:50,000. This type of map will be of direct use to advisors and farmers who may suspect cobalt deficiency problems in animals.

The soil trace element maps produced this year formed part of the exhibits displayed at Agricultural Shows throughout Scotland from Ayr to the Black Isle and generated considerable interest. A technical note entitled "Soil trace element maps"[4] was prepared for distribution at the agricultural shows and other meetings.

Papers discussing the role of soil data in the assessment of geochemical and environmental influences on trace element supply[5] and relationships between trace element availability and the soils and geology of the Aberdeen area[6] , presented at the TEMA-5 conference in Aberdeen, have now been published. A paper on the trace element mapping of Scottish soils still awaits publication[7].

Investigations on the distribution of lead in Scottish soils have continued. Very high concentrations of lead have been found in the surface horizons of uncultivated profiles on the Southern Uplands and on the Campsie Fells, Pentland Hills and Ochil Hills bordering the Midland Valley between Glasgow and Edinburgh. On the other hand, comparable topsoils from the Isle of Mull on the west coast, Aberdeenshire in NE Scotland and the Orkney Islands contain relatively low concentrations. Topsoils at eighteen locations with total values between 101 and 830 mg Pb/kg were from areas ranging in altitude from 130 to 840 m, mean 380 m and with loss-on-ignition values between 23 and 94%, mean 71%. The proportion of the total lead extractable by 0.05M EDTA in these soils averaged 60%. It appears that the high lead concentrations have arisen largely from widely dispersed atmospheric lead which has been intercepted and accumulated in upland areas or deposited with the increased amounts of rainfall at higher altitudes.

The release of lead from soil minerals in the subsoils of profiles has been investigated by analysis of particle size separates and the form of lead in both mineral subsoils and in organic topsoils examined using sequential extractions. It was concluded that atmospheric sources contribute a major portion of the lead in uncultivated upland topsoils in south and central Scotland and that much of this lead becomes strongly complexed by soil organic matter. The release of lead by the weathering of minerals in profile subsoils is enhanced by impeded drainage conditions. This causes increased breakdown of primary minerals, including biotite, and a high proportion of the released lead is held *in situ* in an exchangeable form. These findings are to be published in the Proceedings of a meeting of the Society for Environmental Geochemistry and Health[8].

Papers on the distribution and mobilization of trace elements in Scottish soils[9] and on the chromium and nickel contents of Scottish soils[10] detailed in last year's Annual Report have now been published.

In collaboration with the British Geological Survey and the Departments of Soil Survey and Mineral Soils, a study of the relationships between trace element concentrations in soils and in their underlying parent rocks has been completed. Some forty elements have been determined in 54 B-horizon soil samples by spark source mass spectrometry and nine elements by direct current arc emission spectrometry. The results are awaiting evaluation.

1001, 3007

A chapter entitled "Occurrence and distribution of selenium in geological materials and soils" has been prepared for a book on the occurrence and distribution of selenium edited by M. Ihnat for CRC Press Inc., covering the literature up to 1983, and this still awaits publication[11].

A paper on the location of trace elements in soil profiles derived from granitic and basic igneous parent materials is to appear in the Transactions of the Royal Society of Edinburgh[12]. The investigation shows that trace elements including Co, Cu, Fe, Li, Mn, Ni, V and Zn contained in the more easily weathered ferromagnesium minerals tend to accumulate in the clay and silt. Elements such as Ti and Zr and also La and Y contained in resistant minerals accumulate in the silt or fine sand. The alkali metals Li and Rb accumulate in the silt and clay, particularly in the granitic soils,

while the alkaline earth metals Ba and Sr occur in greatest concentrations in the sands due to their being held largely in resistant feldspar minerals. On release these latter elements are not strongly absorbed by the clay. 3007

In collaboration with the Department of Mineral Soils, studies of the weathering and release of trace elements in hydrologic sequences of soil profiles of the Strichen, Thurso and Ettrick Associations have continued. Analyses of particle size separates from the Strichen and Thurso Association soils have been completed while those of the Ettrick Association soils are in progress. 1061, 3007

A paper on the processes of mobilization and immobilization of iron in thin iron pan formation is to appear in the Proceedings of the North of England Soils Discussion Group[13]. The balance of iron between the horizons of selected podzols has been calculated and the proportion of the total translocated iron concentrated in the thin iron pan horizons estimated at around 10 per cent. The compositions of twelve iron pans from Scottish soils were investigated by chemical extraction techniques, Mössbauer and XRD analysis; the principal components were found to be goethite and ferrihydrite. 3007, 3803

A keynote lecture on soil contamination problems has been published in the Proceedings of an international conference on Chemicals in the Environment[14]. Contamination of soils by heavy metals is generally much more persistent than that arising from contamination by most organic chemicals because the latter are more susceptible to degradation by natural soil processes. The abstract of a paper on cobalt, copper and molybdenum in Scottish soils is to appear in the Proceedings of the Nutrition Society [15]. In order to examine the distribution of farms with soils containing high amounts of extractable molybdenum these have been plotted on a map of north-east Scotland. This shows that the farms are concentrated mainly in the areas of Caithness between Thurso and Wick, in Easter Ross particularly around Invergordon, in Aberdeenshire between Fraserburgh and Peterhead and along the Ythan Valley and also in the area west of Nairn. There are also farms with high-molybdenum soils scattered along the valleys of the rivers Spey and Dee.

A paper describing the design of the soil database, which contains trace element data generated spectrochemically, has now been accepted for publication[16]. 1001, 3007, 8802, 9802

Trace Element Availability and Soil Plant Relationships

Analyses of 96 lucerne samples from a second pot experiment carried out in collaboration with the Department of Soil Organic Chemistry to examine the effects of added peat and lime to ameliorate the effects of copper toxicity in soils have recently been completed. Analysis of the pot soils sampled at the end of the earlier experiment reported in last year's Annual Report have also been completed. The amounts of copper extractable by 0.43M acetic acid have first been determined and the soil residue remaining extracted with 0.05M EDTA. The sum of these two extractable values agrees closely with the amount of copper removed by a single extraction

with 0.05M EDTA. This confirms earlier indications from soil profile studies that the acetic acid extracts exchangeable copper while EDTA extracts both exchangeable and organically complexed copper from soils.
3007, 3008, 4022

Plot soils sampled in 1985 from the long-term experiment on the effects of adding heavily metal-contaminated sewage sludges to soil at the Luddington Experimental Horticulture Station have been analysed for both acetic acid and EDTA-extractable trace elements. These results show that the extractable levels of Cd, Cr, Cu, Ni and Zn are very close to the concentrations in soils sampled in 1981 (Annual Report No. 54, 1984, page 74). There has thus been little decrease in extractable metal contents in the soil at this site over the period of 17 years since the sludges were applied.

Clover samples taken from the same experiment at Luddington by staff of the Agricultural Development and Advisory Service during 1985 have now become available for multielement analysis. It is anticipated that the analysis of these samples will confirm the high persistence of nickel and zinc that is readily extracted by dilute acetic acid and by EDTA. Among the elements being monitored are Cd, Mo and Pb.

Analyses of 76 samples of pine needles from the forest sewage sludge disposal experiments at Montreathmont near Brechin and at Ardross near Tain have been completed. Concentrations of copper and zinc in needles from a 40-year old Scots pine stand at Montreathmont appear to be little affected by sludge treatments. At Ardross, however, where young trees were planted in 1984 on plots treated with sewage sludge in 1983, the first sampling of needles of Sitka spruce show increased concentrations of copper and zinc as a result of sludge treatment. 3007, 3008

A citation classic reporting the work on trace elements in sewage sludges (Annual Report No. 52, 1982) has been included in a Compendium of Contemporary Classics in Plant, Animal and Environmental Sciences[17].
3007

Soil profiles, taken earlier at experimental treatment plot sites where cobalt and/or copper have been added to soils deficient in these elements, have been analysed for extractable metals. Copper was applied at four different locations up to 25 year ago and cobalt at one site about 10 years ago. The profiles were sampled to a depth of about 1 metre and the results show that most of the cobalt and copper is retained in the upper 0 – 25 cm horizon.

Copper added at a rate of 6 kg/ha might be expected to increase the topsoil total copper concentration by about 3 mg/kg. The increases in EDTA-extractable copper at the four different locations were 0.87, 0.72, 0.74 and 0.93 mg/kg, mean 0.82 mg/kg. About 25% of the added copper therefore remains extractable by EDTA while the remainder is fixed in a less soluble form. At one site where the untreated soil contained 0.81 mg/kg extractable copper, the application of 6 kg Cu/ha increased the extractable copper by 0.93 mg/kg. The application of 30 kg Cu/ha might therefore be anticipated to increase the extractable content to $0.81 + (5 \times 0.93) = 5.46$ mg Cu/kg which is very close to the value of 5.74 mg Cu/kg obtained by analysis. The application of 6 or 30 kg Cu/ha to this soil results in the same

proportion of the added copper remaining in extractable form after 25 years. The prolonged residual benefit of copper treatment in terms of yield of cereal grain was still apparent at this site 25 years after copper application. 3007, 3008, 7042

Investigations carried out in collaboration with the Department of Microbiology on the effects of killing the soil biomass by fumigation on the extractability of trace elements have continued. Soils of the Corby and Countesswells Associations with relatively low EDTA-extractable manganese contents have been examined and fumigation was found to have small effects on water and neutral molar ammonium acetate extractable trace and major elements. Fumigation of topsoils of the Stonehaven and Laurencekirk Associations caused an increase in ammonium acetate extractable manganese by a factor of 2 in both soils. Air-drying caused much greater increases in extractable manganese. The effects on water extractability were less consistent, but air-drying again caused greater increases in manganese extractability than fumigation. The effects of fumigation or air-drying on the other trace and major elements were relatively small. 3007, 6027

A poster reporting the use of 2-ketogluconic acid as an extractant in soil profile trace element studies has been published in the Transactions of the 13th Congress of the ISSS[18]. 3007, 4029

Close collaboration has been maintained with the Rowett Research Institute (RRI) and the North of Scotland College of Agriculture (NOSCA) in studies with ammoniated barley straw. Sub-samples of straw used by the RRI and NOSCA in a recent animal feeding trial were digested *in vitro* for 48 hours at 40°C in a citric acid — sodium phosphate buffer at pH4.6, using a commercial cellulase (BDH, *Trichoderma viride*). The Cu content of the buffer was adjusted in the range 50 to 1000 μg/ml. In this range of initial buffer Cu-contents, it was found that both the untreated and the ammoniated straw absorbed Cu. However, the ammoniated straw reduced the Cu content of the digest by about 30 to 50%, whereas the untreated straw reduced the content by only 10-30%. It is planned to examine the effect of pH on Cu absorption by straw so that the possible implications for animal nutrition can be assessed. 3008

Spectrochemical Methods for Analysis

Arc emission

The procedure described last year (Annual Report No. 55, page 50) for the combined d.c. arc analysis of separate acetic acid and ammonium acetate soil extracts, for Co and Mo respectively, has been reported in detail[19]. The arc procedure for determining Al after coprecipitation with Fe, also mentioned last year, has been published[20]. The related simpler procedure for Al using the same conditions for precipitation, but employing infrared absorption for the determination, was presented as a poster at an international conference (SAC 86/3rd BNASS) held in Bristol. The note describing the use of 2-mercapto-4-n-propylacetanilide for precipitating Pb from solution at pH 5.2 has also been published[21]. 3007, 3008, 3010

In collaboration with the West of Scotland Agriculture College, trace elements in soil and plant samples from a copper dose response trial in lambs have been determined. Ammonium acetate extractable molybdenum in 41 soils and total molybdenum, copper and titanium in 24 of the soils were determined using direct current arc emission methods. 3903

Soil extraction using a cell-roller

A cell-roller machine, whose advantages for the preparation of soil extracts were mentioned previously (Annual Report No. 52, page 61) has been evaluated for the determination of EDTA-extractable Cu and Mn. The results obtained with the cell-roller followed by centrifuging the extracts correlated very well with those obtained by the procedure in use since 1955, which uses an end-over-end shaker and gravity filtration. In the course of the investigation, it was noted that the Mn content of the EDTA-extract increased considerably, for some soils, during the filtration stage. A detailed report has been prepared[22]. 3007, 3008, 3010

Atomic Absorption Spectrometry

The Instrumentation Laboratories IL-751 and the Pye Unicam SP-9 atomic absorption spectrometers have been used for trace element determinations in a large number of non-routine samples generated in this and other departments of the Institute.

The IL-751 has been primarily used for the determination of Cu, Zn and Mn in soil solutions in an investigation of the mobilisation of trace elements in the rhizosphere of barley[23]. Approximately 1500 flame analyses and an equal number of graphite furnace atomic absorption determinations have been carried out. Several hundred flame atomic absorption determinations have been carried out on fractions from chromatographic columns prepared in the Department of Spectrochemistry and from experiments carried out in collaboration with the Department of Plant Physiology concerned with the isolation and determination of the copper-containing protein plastocyanin. Similarly, several hundred cobalt determinations have been carried out on solutions of plant ashes from the Department of Plant Physiology in experiments concerned with the uptake and transport of cobalt in wheat seedlings. Other determinations include cobalt in drainage waters, copper in buffer mixtures, and alkali earths and transition metals in plant nutrient solutions and distillery products. Chromatographic procedures for the isolation of copper and zinc prior to analysis by thermal ionisation mass spectrometry are currently being investigated and flame atomic absorption is being used to measure the amounts of these elements in the column fractions.

The work previously described (Annual Report No. 55, p. 81) on the direct determination of cobalt in acetic acid extracts of soils by graphite furnace atomic absorption spectrometry is complete[24] and the method verified. The IL-751 has also been used in the flame mode for the screening of SWAP water samples for copper and zinc. Although many of the

samples have measureable zinc contents (> 25 μg/l), levels of copper are generally below the limit of determination (15 μg/l).

3011, 3069, 3074, 3803/4803, 3809, 5806

The Pye Unicam SP-9 atomic absorption spectrometer has been used exclusively for graphite furnace work and has been interfaced with an Apple micro-computer. Transient absorbance signals are digitised and the time versus absorbance profiles recorded. With this system samples can be analysed, the data processed, and reports printed out with considerable saving in time and effort.

This instrument, in conjunction with sample preparation using the Trace-O-Mat combustion apparatus, has also been used for the determination of selenium in plant materials[25]. A large percentage of the instrument time has been taken in the determination of part per billion levels of lead and cadmium in water samples and approximately 2000 determinations have been carried out for the SWAP programme. Additionally the instrument has been used for the determination of low levels of cobalt and silver in solutions of plant ashes from the Department of Plant Physiology.

3011, 3809

The Varian AA-6 atomic absorption spectrometer has been used for the cold-vapour atomic absorption determination of mercury, and also for atom-trapping work. A paper describing the determination of cadmium in calcium chloride extracts of soils using the latter technique has been published[26]. Another paper reporting the use of the technique for the determination of trace elements in soils, waters and liver samples has been submitted for publication[27]. It is planned to relocate this instrument and dedicate it to the determination of selenium and other hydride-forming elements such as arsenic by hydride generation/atomic absorption spectrometry using air-segmented or flow-injection auto-analysis techniques. A system comprising a multi-channel pump, autosampler, and an electrically-heated quartz T-cell has been constructed. The atom-trapping capability has been retained by transferring the burner assembly of the Varian AA-6 instrument, after some modification, to the Varian-1275 spectrometer. 3011

The number of routine determinations of the major cations Ca, K, Mg and Na for advisory and other purposes this year have continued at a level of 115,000 which is very close to the numbers achieved during the past two years. A little over 10% of this total were analyses carried out for the SWAP programme. The number of trace element determinations overall were similar to last year though the number of advisory cobalt, copper and molybdenum analyses decreased slightly.

1001, 2056, 3007, 3011, 5050, 7038, 7041, 7043, 7047, 7048

As part of an international study on the trace element composition of basic foods being conducted by the FAO European Cooperative Network on Trace Elements, samples of wheat, potato and dried milk have been collected from centres in Scotland and processed under contamination-free conditions ready for subsequent analysis. Under contract from the Commission of the European Communties, Community Bureau of Reference, a sample of sea lettuce and samples of river, lake and estuarine

sediments are being analysed for several trace and major elements. The data, together with those from other laboratories will be used to certify these materials as new standard reference materials.

In collaboration with the West of Scotland Agriculture College ninetysix samples of herbage taken from a copper dose response trial in lambs have been analysed for selenium. 3903

A paper reporting the development of a multi-sensor system using coated piezoelectric crystal detectors for the determination of airborne contaminants such as atmospheric ammonia together with moisture and temperature has now been published[28]. 3011

The clean laboratory facilities mentioned in last year's Annual Report No. 55 p. 87, are nearing completion. This will provide filtered-air conditions and better control of contamination which is essential for the preparation of samples for thermal ionisation mass spectrometric and graphite furnace atomic absorption analyses.

Trace Metal Speciation

This is an expanding area of interest in the Institute and elsewhere, particularly in relation to nutrition and toxicology.

Plastocyanin, a copper-containing protein of molecular weight 10,000-20,000, has been found in a variety of higher plants and algae. It has been suggested that copper bound to this protein survives the sulphur-rich environment of the rumen and its occurrence in the diet of ruminants is a possible factor in controlling copper availability. HPLC gel filtration and ion exchange, in conjunction with detection by UV absorption spectrometry and flame atomic absorption spectrometry, have been used to isolate this protein from rye grass. This investigation has been carried out in conjuction with the Department of Plant Physiology and it is hoped that methods for the quantitative determination of the protein in fresh and dried grass can be established. 3011, 5806

The speciation of aluminium in surface and soil profile waters is a major component of the SWAP project. An automated air-segmented system for the spectrophotometric measurement of monomeric aluminium species using pyrocatechol violet has been in operation throughout the year and over 3000 determination have been made. The effects of sample storage, filtering and other parameters which may affect the categorisation of aluminium in natural water samples is at present being investigated. Leaching experiments with soils taken from various horizons of an alpine podzol have also been carried out. The effect of various organic and inorganic acids on the form of aluminium in the element fractions are being investigated. 3809

Reflectance Spectroscopy

In collaboration with the Remote Sensing Unit and the Department of Soil Fertility the single-beam, two-band portable radiometer (Annual Report Nos. 54 and 55) has been employed to monitor the growth and development of a variety of crop types, including potatoes, spring barley and oil-seed rape. The trial crops were subjected to a wide range of stress

conditions. A report detailing the results obtained from potato trials has been accepted for publication[29] and other publications are being prepared. A MISR Technical Note is available that describes this work in general terms[30]. The field trials served to demonstrate the radiometer to be robust, easy to use and capable of providing an excellent non-destructive method of recording the development of vegetative growth. Considerable interest in the design and application of the instrument has been shown by other Institutes and Colleges and several radiometer units have been constructed in the Department of Spectrochemistry and sold to the National Remote Sensing Centre (Farnborough), the University of Ulster and Salford University. It is anticipated that other agricultural and educational estabishments will also be interested and may purchase instruments.

The transmission characteristics of the optical filters employed in the two-band radiometer are selected to encompass wavelengths of high absorbtion (red) and high reflection (near infrared) of light from a plant canopy. By ratioing the recorded reflection values using these two bands, a single figure is provided that is very sensitive to vegetative growth and highly correlated with canopy expansion and ground cover. Light absorption at red wavelengths is due to chlorophyll pigments in plant tissue whilst the high reflectivity of near-infrared radiation (800-1200nm) is a function of light scattering mechanisms within the leaf structure. With the aid of a double-beam radiometer these different plant reflection characteristics can be studied as independent variables without interference from changing ambient light conditions. Such an instrument, a double-beam, two-band radiometer (Annual Report No. 55), has been undergoing field trials. A potato trial and mixed herbage trial plots were studied and the preliminary results demonstrate the value of recording the reflection intensity in both wavelength bands. On a range of mixed grass and broad leaf vegetation trial plots, the reflectance characteristics were observed to vary markedly depending on the crop composition contained in the field-of-view of the instrument. Subsequent statistical analysis of the two-band reflection data produced a linear discriminant function which served to separate the narrow leaf and broad leaf plant species. The potential of this rapid and non-destructive optical technique to distinguish between plant types and provide characteristic growth curve data for a target of mixed species will be examined during forthcoming trials within the Institute grounds.

The portable reflection radiometers developed in the Department of Spectrochemistry provide a simple and inexpensive means of monitoring vegetative growth and the interaction of light with a plant canopy. The amount of radiant energy absorbed by a leaf canopy is one of the most important variables employed in monitoring and modelling crop development and the application of radiometric data in plant growth modelling systems is being investigated. 3810

Radiofrequency Plasma Emission

During this year, a wide variety of elements in various samples including soil extracts, plant digests, natural waters and minerals have been

determined in support of the research objectives listed below. The demand for analysis has continued at a high level with the instrument running at capacity. Completion of the work on molybdenum has provided a method for the determination of this element in ammonium acetate soil extracts down to the 10 ng/g level. There has been a substantial increase in demand for boron determinations and for the first time, the determination of phosphorus in acetic acid soil extracts has been undertaken.

2054, 3011, 3007, 3008, 4801, 7041, 7042

The work on nebulizers and spray chambers for inductively coupled plasmas is nearing completion. Various spray chamber designs have been evaluated using laser particle sizing equipment at the Long Ashton Research Station. A cyclonic design was found to give best all round performance and in combination with the patented Conespray nebulizer, has worked very successfully on the Department's plasma spectrometer. Development of the original Conespray concept has further improved the performance, and funds have been made available from the British Technology Group for its commercial exploitation. A larger scale device was designed for evaluation for environmental testing of gas turbines at the Royal Aircraft Establishment, Farnborough. 3011

A paper on nebulizers and spray chambers has been accepted for publication in the Journal of Analytical Atomic Spectrometry[31]. Reviews on recent developments in analytical spectrometry have been published in Chemistry in Britain[32] , Analytica Chimica Acta[33] and the Journal of Analytical Atomic Spectrometry[34,35].

Laser Spectroscopy

A project to use infrared laser long-path absorption spectrometry to study field emissions of N_2O and their contribution to denitrification has been proposed jointly with the Department of Soil Fertility for consideration under the new initiatives scheme. The staffing of this project has been affected by the transfer of posts to SCRI. 3011

Spark Source Mass Spectrometry

The spark source mass spectrometer has continued in use for the multi-element analysis of various samples including four soil profiles (a peaty podzol with iron pan, a brown forest soil, an iron podzol and a peaty gley) in an investigation into the accumulation of other elements together with the iron in these types of profile. Although the analyses are complete, the data have still to be processed completely. Further human foetal lung samples have been analysed as part of a programme to establish the trace element levels in human foetal organs and tissues, with reports being published on the analysis of foetal livers[36] and kidney samples[37]. A chapter entitled "Inorganic trace analysis by mass spectrometry" has been submitted for publication in a book on the applications of mass spectrometry in food science[38].

TABLE 3.1 Ratio of $^{87}Sr/^{86}Sr$ for six separate analyses

0.710227	0.0006%	0.710229	0.0005%
0.710237	0.0006%	0.710249	0.0007%
0.710239	0.0006%	0.710238	0.0006%

With manpower resources transferred to the thermal ionisation mass spectrometer and refitting of the laboratory, it is no longer possible to operate the instrument continuously, but the capability is being maintained and it is intended to continue to use the instrument for multi-element analyses of selected soil profiles. 3007, 3010

Thermal Ionisation Mass Spectrometry

The VG Isotopes 354 thermal ionisation spectrometer (TIMS) has been in operation for just over a year. Methods available for the isotopic analysis of strontium and lead have been used to analyse simple salt solutions in order to obtain experience with the operation of the instrument and to assess its analytical capability. Subsequently new methods have been developed for the isotopic analysis of zinc and copper, elements of considerable interest in nutrition studies and which have been relatively little studied using TIMS.

The filament loading procedure has been studied to find the optimum conditions for the analysis of zinc and copper. The simplest method of filament loading, as used for strontium analysis, involves drying the sample and phosphoric acid on to a metal filament (rhenium or tantalum) which, when raised to the required temperature, provides the hot surface for both vaporisation and ionisation of the element and produces a very stable beam of low energy ions. As an indication of the precision achieved, Table 3.1 gives the values obtained for the $^{87}Sr/^{86}Sr$ ratio for six separate analyses of a strontium standard.

Not many elements are amenable to this simple method, however, and a commonly-used modification, as used in lead analysis, is the silica-gel technique in which the sample and phosphoric acid are dried onto a spot of silica gel deposited on the filament. This gel inhibits vaporisation of the atoms so that there is a much greater probability of migration to the filament surface and ionisation. This technique has been adopted for zinc and copper analyses and all aspects, including drying temperature, relative concentrations and volumes of the reagents, and heating temperature of the filament after sample loading, have been investigated to obtain optimum and reproducible loading conditions. During analysis zinc produces a very stable ion beam and a sample loading of 1 μg can maintain a high beam current of 3×10^{-11} A for many hours. Furthermore the multisotopic nature of zinc allows one measured ratio to be used to normalise the other ratios. The internal precision and sample-to-sample reproducibility thus obtained is illustrated in Table 3.2.

Copper, on the other hand, requires a 2 μg loading to produce a weaker beam (3×10^{-12} A) of shorter duration and, with only two stable isotopes, cannot provide the ratios needed for normalisation. As a result, although the internal precision is $\leqslant 0.01\%$ for copper ratio determination, an

TABLE 3.2 Isotopic analysis of six zinc nitrate or sulphate samples

	$^{64}Zn/^{66}Zn$		$^{64}Zn/^{68}Zn$		$^{67}Zn/^{68}Zn$	
1	1.7586	0.001%	2.6334	0.004%	0.2174	0.002%
2	1.7585	0.002%	2.6340	0.002%	0.2178	0.004%
3	1.7584	0.002%	2.6341	0.003%	0.2168	0.006%
4	1.7583	0.002%	2.6340	0.005%	0.2176	0.005%
5	1.7582	0.002%	2.6343	0.005%	0.2176	0.005%
6	1.7585	0.005%	2.6344	0.005%	0.2173	0.009%

accuracy of only about 0.05 to 0.1% can be achieved. With experience and technique development, it should be possible to improve this. To obtain this level of precision it is necessary to analyse pure analyte salts and a simple ion-exchange chromatography procedure is being developed to isolate the analyte from samples. Anion exchange in HCl solution allows separation of copper, iron and zinc from each other and from most other metals which are not retained on the resin. As only 1 or 2 μg copper will be present in whole samples of blood plasma, an electrodeposition system has been set up to allow concentration of the copper, either from sample digests directly or from the chromatography fraction. This system will also allow collection of low levels of lead from plant samples for environmental studies.

Following development of the chromatographic system on synthetic mixtures, it is now being used for the analysis of human faecal and plasma samples. A collaborative study has been started with Dr. P. Aggett of Aberdeen Royal Infirmary in which subjects are fed diets enriched in ^{70}Zn and given enriched ^{67}Zn intravenously. It is intended to determine simultaneously the rate of absorption of ^{70}Zn and rate of loss of ^{67}Zn through the gastro-intestinal tract. This capability of very precise isotope ratio measurement will be of considerable value in human nutrition studies for which stable isotope tracers are prepared, but for which the analytical techniques have been either unavailable or unable to provide sufficient precision. In animal studies radioactive tracers can still be used for some elements, in particular copper, but the short half-life of the radioactive isotope restricts the studies possible. A project is to be started in collaboration with the Rowett Research Institute on the metabolism of copper in animals using stable isotope tracers.

With these projects underway, attention will be given to the isolation and analysis of lead from environmental samples and also for the very accurate determination of lead concentrations using the isotope dilution method.

3074

Surface Water Acidification Programme (SWAP)

The thirty soil profiles sampled to characterise the three SWAP sites have been analysed for total, 0.05M EDTA and 0.43M acetic acid extractable trace elements. The abnormally high 0.05M EDTA-extractable lead and zinc contents of the upper two horizons of the Kelty profiles reported earlier are confirmed by the analyses for both total and acetic acid-extractable contents. The mean contents of lead, zinc, copper and cadmium in the

TABLE 3.3 Mean topsoil contents of trace elements in 10 soil profiles from each site as mg/kg

	KELTY			LOCH CHON			MHARCAIDH		
	TOTAL	EDTA	HOAč	TOTAL	EDTA	HOAč	TOTAL	EDTA	HOAč
LEAD	172	119	7.3	111	64	4.4	21	14	1.2
ZINC	68	58	28	49	34	15	35	9.5	5.1
COPPER	11	5.3	0.48	8.9	3.6	0.36	1.8	0.50	0.2
CADMIUM	-	0.99	-	- 0.41	-	-	0.13	-	

upper horizons of the three groups of profiles decrease from Kelty to Loch Chon to Allt a Mharcaidh as shown in Table 3.3.

These differences in total and extractable heavy metal contents between the three sites are probably attributable to differences in atmospheric deposition in the three areas. The differences in the amounts of the metals extracted by 0.05M EDTA and by acetic acid suggest that a high proportion of the lead and copper in the profile topsoils is held in organic combination. The amounts of acetic acid-extractable zinc (exchangeable) are much closer to the EDTA-extractable zinc values (exchangeable and organically complexed) than is the case for either lead or copper. Zinc thus appears to be less strongly complexed by soil organic matter than lead or copper.

High acetic acid and low EDTA-extractable aluminium in soil profile B-horizons can sometimes be a useful indicator of the presence of protoimogolite, as is an Al/Si content ratio between 2 and 6 in acetic acid extracts. On the basis of these criteria, B, Bx or Bs horizons from four podzol profiles from the Allt a Mharcaidh site appear to contain this amorphous gel form of aluminium which may be released into soil waters by acidification. The presence of this form of aluminium in the soil has been confirmed by infrared spectrometry. There is little evidence to indicate the presence of protoimogolite in the Kelty or Loch Chon profiles.

Work has now started on analysis of the replicated soil profiles from which soil water samples are being taken from A, B, and C horizons. The Varian 1275 flame atomic absorption spectrometer, funded by SWAP, is being used for these and other SWAP analyses.

Methods for the speciation of aluminium in surface and soil waters have been developed by Mr R. MacMahon working under a SWAP funded Ph.D. studentship. In all three catchment areas, the greatest proportion of the aluminium is in the monomeric form. In general, the non-labile fraction comprises between 20 to 40% of the total monomeric aluminium, being greater in the Kelty catchment where there is a higher organic matter loading. The organic aluminium contribution is generally small and represents a 25-30% increase on total monomeric aluminium values in most cases. It appears that the Kelty catchment has greater aluminium levels in most waters including stream, litter, stem flow and soil profile waters, compared to waters of the Chon and Mharcaidh catchments.

Leaching experiments have been carried out in the laboratory with soils from four horizons of an alpine podzol from Allt a Mharcaidh. The soils were leached with sulphuric or citric acid over a period of six weeks and amounts of Al species, Ca, Mg and sulphate measured. Both acids leached similar amounts of total Al from the soils except for the A-horizon soil

where sulphuric acid removed twice as much Al as citric acid. The amounts of Ca and Mg leached were generally small with the greatest amounts being removed from the A-horizon soil during the first week. The Bhs horizon showed a much greater sulphate adsorption capacity than samples from other horizons of the profile.

Analyses of some 2000 water samples for trace elements have been completed using flame and graphite furnace atomic absorption methods as reported under the section on *Atomic Absorption Spectrometry* and these results are being evaluated. Assistance in the analysis of these samples was provided for some weeks by Miss Diane Cowie, a student from Robert Gordon's Institute of Technology. 3809

Molecular Spectrometry of Soil Components

Infrared Spectroscopy

Podzolization is frequently encountered in upland and marginal land. It is a relatively rapid soil forming process which occurs widely in temperate climates. The process is known to involve the translocation of Al, Fe and Si as protoimogolite from upper, acidic, weathering horizons, to lower more basic horizons where they are deposited as allophane and imogolite. Because these minerals have large surface areas and are active in ion exchange reactions, they will be involved in the movement and availability of nutrient ions. It is, therefore, important to understand the mechanism of podzolization fully. Earlier studies of the reaction which forms protoimogolite and imogolite have suggested that translocation could proceed via a purely inorganic mechanism (Annual Report Nos. 53, 54), but it seems likely that, because of their ubiquity in soil, organic molecules of plant and microbial origin could be involved throughout the podzolization process, not simply in the weathering of primary minerals.

Results from a series of purely inorganic syntheses indicated that the time scale for formation of imogolite in a temperate podzol was likely to be of the order of a few hundred years (Annual Report, No. 55). However, earlier work on the effect of a range of anions on the formation of imogolite indicated an increased rate in the presence of acetate. To explore the significance of this observation and its relevance to metal complexation and the role of vegetation type in podzolization, work using infrared spectroscopy and electron microscopy is in progress on the influence of a selection of organic acids on the formation of imogolite. This may help to identify possible organo-aluminium species in podzolic environments. A review of the sources and speciation of aluminium and silicon in natural waters has now been published[39]. Further papers stressing the transportation of Al as an inorganic species in podzols[40] and the possibilty that similar mechanisms may produce pedogenic layer silicates under appropriate soil conditions[41] have been submitted for publication. A paper on the structure and genesis of allophane and imogolite[42] still awaits publication. 1060, 3005

Infrared spectroscopy continues to make a contribution to the SWAP programme by providing information on the presence of protoimogolite allophane and imogolite in soils from the catchment areas under

investigation, and methods are being developed to try to identify aluminosilicate species in natural acidic waters. As discussed above, these minerals are formed during normal podzolization, but they are acid labile and may be dissociated and mobilized by acidification. In this programme, methods are required for the analysis of Al, and in a new development, IR has been used to determine submicrogram amounts of Al as its 8-hydroxyquinolate (oxinate) using Fe oxinate as internal standard. The method is rapid, free from interferences and has been computerized to minimize operator error. Papers on this method and on the related identification of metal-oxygen stretching vibrations in a series of oxinate complexes of trivalent metals are in preparation. The methods were presented in poster form at the SAC 86/3rd BNASS Conference in Bristol.

Infrared spectroscopy continues to play an important role in studies of soil clays and minerals. In a recent international collaborative investigation of kaolins of different origins, IR combined with electron microscopy, DTA and XRD to identify important differences in mineralogy, and in sizes and shapes of kaolinite particles which helped to define the thermal conditions present during their formation[43]. 3005

The applicability of IR techniques to studies of crystalline and non-crystalline soil components has proved vital in identifying both goethite and ferrihydrite in iron pans from a range of locations. This technique again in conjunction with XRD and Mössbauer clearly shows that an alkali treatment used to concentrate the crystalline iron minerals resulted in the conversion of ferrihydrite to goethite. A paper on the general applicability of IR to soil studies has now been published[33] , and a detailed chapter on the use of IR in studies of inorganic systems still awaits publication[44]. In collaboration with the Department of Mineral Soils, a review paper describing the roles played by the oxides of manganese, iron and aluminium in controlling the concentrations of anions and cations in soil solution has been submitted for publication[45]. 3005, 3803

In a collaborative study with the Departments of Soil Organic Chemistry and Mineral Soils on the effect of swelling clays such as montmorillonite on the activity of soil enzymes, IR has been used in conjunction with XRD to elucidate the general reaction between clays and proteins. Preliminary results for IR have shown that bovine serum albumin is absorbed in a form which is indistinguishable from that of bulk protein at all protein-to-clay ratios from 0.1 to 4, indicating that the molecular shape (α -form) has not changed on adsorption. After heating to remove adsorbed water however, shifts in position of N-H bands from secondary amide groups suggest that a proportion of protein molecules on the clay surface has adopted the more extended β -form, particularly for the protein, up to ratio 0.1 which is adsorbed in interlayer positions. Additional protein is thought to be sorbed on external surfaces as multilayers. Further work is planned to elucidate the orientation of sorbed molecules and the effect this might have on enzyme activity in soil. 3005, 4064

In contrast to the slow changes produced in minerals by weathering, decomposition of plant and animal tissues in soils and in animals is relatively rapid and is essential for the good conditioning of both systems. It

is therefore important to know and understand how these tissues are degraded, if possible by using direct methods of analysis such as reflectance IR spectroscopy. This approach was used successfully in a collaborative investigation with the Rowett Institute on the digestibility of cereal straw in sheep rumen. Multiple internal reflectance (MIR) spectroscopy was used to monitor the chemical changes in many of the straw components. In a paper in preparation, it is shown from an examination of the outer and inner surfaces of wheat and barley straw, that degradation by rumen enzymes occurs predominantly at the inner surface, where polysaccharide is depleted and lignin accumulates, and that the outer surface, protected by the hydrophobic waxy cuticular layer, resists attack. An alkaline pretreatment, known to improve the digestibility of straw, degrades the outer layer by hydrolysing acetyl and possibly other ester groups and dissolving silica particles, and thereby increases access of rumen enzymes through this layer to the interior polysaccharides. 3017

This direct reflectance method of analysis by MIR shows great potential, and work is in progress with the Department of Soil Organic Chemistry on an analogous study of the effect of incubation in soil on the degradation of cereal straw and ryegrass. Preliminary results suggest that it follows the same course as that in rumen digestion described above. In a further experiment designed to follow the degradation in soil of *Lemna* species, IR will again be used to monitor the changes which occur during incubation. The initial results for fresh tissue have shown that *Lemna gibba* is significantly more proteinaceous than *Lemna minor*, and that for both species, senescence results in loss of protein and modification of the residual cell wall polysaccharides. However, for *L. gibba* much greater accumulation of calcium oxalate occurs than for *L. minor*, a property which along with the higher protein content may serve as a means of distinguishing the species. IR has also shown that the chemistry of *Lemna* species is related to morphology, the gibbous form of *L. gibba* having a significantly greater protein content than the flat form, and also a different type of oxalate. The implications of these observations for species identification, and the possibility of using reflectance spectroscopy as described above are being investigated further. Related work in collaboration with the Department of Microbiology involves the use of MIR in assessing changes in leaf surfaces during composting. This supplements information from IR analysis of invertebrate faecal pellets and provides information on the nutritional requirements of soil fauna such as woodlouse and termite. A paper on the nature of the components in the exoskeleton of the woodlouse still awaits publication[46], and the results of a related IR study of the degradation of these components in soil has been presented as a poster at the 14th International Congress of Microbiology, Manchester, 1986. A joint paper with the Department of Soil Organic Chemistry on the relevance of polymaleic acid as a humic substance model is still awaiting publication[47], and a response in favour of the non-aromatic nature of soil fulvic acid has been published[48]. 3017, 6027

In further collaboration work with the Department of Microbiology on fungal metabolic products, IR and UV spectrophotometry have shown that

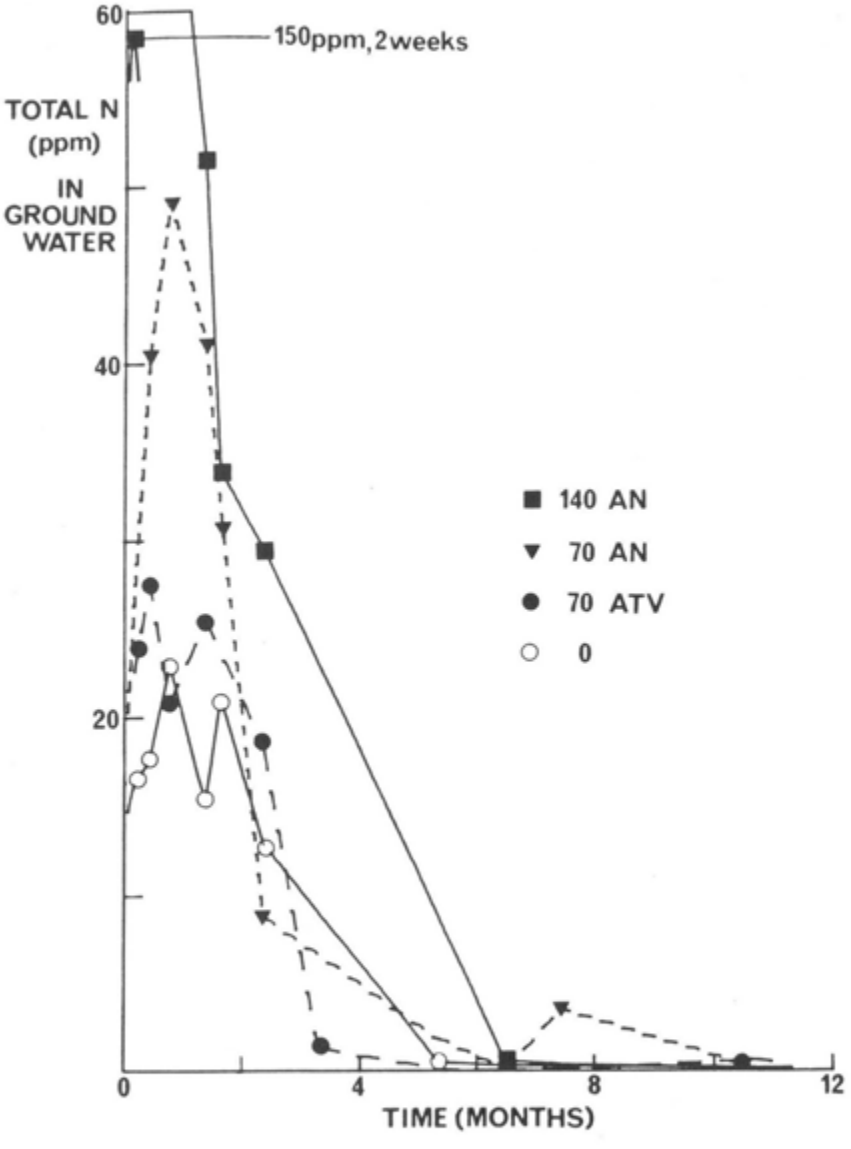


Fig. 3.1 Total N in ground water (9″ depth) leached from annual ryegrass plots treated at sowing time with ammonium nitrate (AN) or ammonia treated vermiculite (ATV) at 140 and 70 KgN/ha.

Penicillium echinulatum produces in well oxygenated conditions a low yield of the antibiotic 5-oxymaltol, a metabolite not previously reported for a fungus. However, a change to more static cultural conditions results in the

formation of a group of products, one of which has been identified by IR as the antibiotic mycophenolic acid. In conjunction with mass spectrometry and ^{1}H NMR spectrometry, IR is currently engaged in identifying the other products formed. These results were presented as a poster at the 14th International Congress of Microbiology, Manchester 1986. 3017, 6026

Results from a ryegrass field-trial set up to compare ammonia-treated vermiculite (ATV) with ammonium nitrate (Annual Report Nos. 53, 54) are now complete. They clearly show that, during the first 2-3 months after seed sowing, the rate of leaching of N from ammonium nitrate plots was up to six times that from ATV plots, Fig. 3.1. Indeed the loss of N from the ATV plots was not appreciably different from that from the plots to which no N fertilizer had been added. Because of variation in the germination and growth of the ryegrass due to variable ground conditions, some of the later grass yields showed large coefficients of variation and, therefore, did not show statistically significant differences between N-treatments throughout the duration of the experiment. Nevertheless visual inspection and earlier yields indicated that ATV performed as well as ammonium nitrate at the same rate of N applied. In a cut taken 16 months after sowing, by which time little or no leached N was detectable in ground water samples from any of the plots, the grass yield from the ATV plot was significantly greater than either the 0-N or equivalent ammonium nitrate-N plots. The observations indicate that N in ATV is not leached into ground water under field conditions. They also show that for ryegrass during the first season's growth, ATV performs as well as conventional N-fertilizer at the same rate of applied N, and that in the second season, sufficient N remains in the ATV to produce a yield of ryegrass 7-23% greater than those from all of the other treatments. 3005, 7048

Mössbauer Spectroscopy

In view of the likely change in research priorities in 1987 most of the work this year has been directed towards completing projects that were already in existence and few new areas of investigation have been undertaken during this period. The main emphasis of the work has been on mineralogical species and has involved both single and multimineral systems.

The paper on the use of Mössbauer spectroscopy in the study of colloidal materials, which was originally reported in Annual Report No. 54, is still awaiting publication[49]. 3005, 3803

The work on illitic clays in collaboration with the Department of Mineral Soils (see Annual Report No. 55) has been extended and is now complete. A paper is currently being prepared in which the nature and origin of associated iron oxide phases are discussed along with the differences in distribution of Fe(III) over the various types of structural site.

A considerable amount of work has been carried out on a related series of smectites using both Mössbauer and EPR spectroscopy. The Mössbauer experiments were performed at ambient temperature, 77K and 4.2K, the last of these measurements being performed in collaboration with the Department of Physics, Liverpool University. The Mössbauer results demonstrate the existence of phases with distinctly different iron

concentrations and a paper on this work is currently being prepared for publication.

Also in collaboration with the Department of Mineral Soils, and the Department of Physics, Liverpool University, we have commenced low temperature measurements of some iron-rich chlorites. Magnetic ordering has been observed at 4.2K and experiments are now continuing over a range of temperatures with the objective of identifying the distribution of iron between the aluminosilicate and brucite-like layers.

Work on the mineral Macaulayite referred to in Annual Report No. 55, has now been completed and a paper submitted for publication[50]. The magnetic properties of the hematite-like layers in Macaulayite have significant differences from those in other hematites and these results are discussed in terms of the previously proposed structure for Macaulayite (Annual Report No. 53). 3005

As an extension of work previously performed in collaboration with the University of Leuven, Belgium on the adsorption of Fe(II) and Fe(III) on clay minerals (Annual Report No. 53), experiments have been initiated using saponite in order to investigate the effects of the source of layer charge on the nature of the adsorbed species. At the present time the results are inconclusive and additional experiments are still needed.

The work on the effects of alkali-treatment on the transformation of poorly-crystalline iron oxides referred to in Annual Report No. 55 has been completed and a paper submitted for publication[51]. Our results show that conversion of ferrihydrite to goethite occurs if there is a small amount of goethite or hematite in the sample to act as a seed for crystal growth. These findings now enable us to explain the differences in observations of various groups of workers involved in assessing the use of the boiling alkali method for concentrating crystalline iron oxides in soil samples. 3005, 3803

Work has also been carried out in collaboration with the Fresh Water Biological Association in an attempt to characterize the forms of iron in some lake sediments. So far this work has had limited success and it appears that, in order to obtain a full characterization of this type of sample, it will be necessary to use temperatures lower than the 77K available in our laboratory. 3803

Most of the experimental work on the reaction of iron with fulvic acid (Annual Report No. 55) has now been completed. A preliminary report has been accepted for publication[52] and a detailed paper is in the course of preparation. The results show the formation of mononuclear complexes over a wide pH range and reduction of Fe(III) to Fe(II) at low pH values. The one remaining problem in this work is in distinguishing the relative contributions of complexed and polymerized species to the doublet Fe(III) component and experiments at low temperatures (4.2K) are currently being performed in collaboration with the Department of Physics, Liverpool University in order to resolve this problem. 3803, 3808

Electron Paramagnetic Resonance (EPR) spectroscopy

Several projects referred to in Annual Report No. 55 have been continued during the current year. Work with low molecular weight complexes of

oxovanadium (IV) is now largely complete and a series of papers based on this work is in the course of preparation. They demonstrate that the EPR parameters are influenced both by the nature of the coordinating group and the existence of strain within any chelate ring. This latter observation may make it difficult in some cases to deduce the coordination environment of vanadium from EPR parameters alone. Further information on the coordination environments of vanadium in amino acid complexes has been obtained by ENDOR (electron spin double resonance) spectroscopy in collaboration with the University of Sheffield. These results are able to demonstrate whether or not nitrogen is coordinated to the vanadium, but they are not able to estimate the number of coordinated nitrogens. Work on the characterization of species adsorbed on clay minerals has been extended and includes a project initiated in collaboration with the Department of Chemistry, University of Essex. Although progress is being made a great deal of additional work will probably be necessary before conclusive results are obtained. 3005, 3803

In collaboration with the Department of Mineral Soils combined EPR and Mössbauer measurements have been performed on a series of smectites. Whereas the Mössbauer measurements have distinguishable phases with distinctly different iron contents, the EPR measurements have identified components with different crystal field distortions. A paper on this work is currently being prepared for publication. 3005

The experimental work on the iron-fulvic acid systems (Annual Report No. 55) is now largely complete and a preliminary report has been accepted for publication. A more detailed paper is currently in the course of preparation. The results show that mononuclear complexes produce a signal with $g = 4.3$, whereas polymeric species give a broad absorption with $g = 2.0$. The sharpening and intensification of this latter feature on reduction of Fe(III) to Fe(II) demonstrates that some ferromagnetic exchange is introduced and at least some of the reduction is associated with the polymeric species. 3803, 3808

Work on the production of free radicals in wheat roots (Annual Report No. 55) has now been completed and a paper accepted for publication[53]. The production of free radicals (half-life$\leqslant$ 3 mins) has been shown to occur as a result of reaction with atmospheric O_2 and it is postulated that organic peroxy radicals are formed. 3806

Experiments in collaboration with the Rowett Research Institute on the effects of diet on free radical production in the hearts and livers of rats has progressed satisfactorily during the year. A method has been developed for trapping short-lived free radicals by the spin-trap 4-POBN and correlations have been observed between the dietary history of the animal and the subsequent level of free radical production in organ homogenates on exposure to O_2. A paper is currently being prepared which shows that there is a direct link between vitamin E deficiencies and free radical production.

The concentrations of free radicals in the seeds of several legumes and brassicas have been measured in an attempt to see if EPR spectroscopy can be used in the non-destructive testing of seed viability. The experiments were largely unsuccessful, primarily because in many cases there were high

free radical contents in the testa from melanin-like species and these masked any effects that may have been the result of membrane degradation through autoxidation of unsaturated fatty acids. A paper on this work has been accepted for publication[54]. 3806

Several experiments have been carried out partly in collaboration with Torry Research Station, with the objective of assessing the usefulness of EPR spectroscopy in detecting the effects of ionizing radiation on various foodstuffs. Our results have shown that stable free radicals are trapped in bone as a result of exposure to radiation and that these free radicals are readily distinguishable from those that occur naturally. In the case of many fruits, increases in free radical contents of seeds are seen on irradiation, but these radicals generally resemble those that occur naturally from melanin-like pigments. Because of the great natural variation in the concentrations of such signals it is unlikely that EPR spectroscopy will offer a general method for identifying irradiated fruit. A number of interesting effects have been seen with materials as diverse as pork fat, scampi shells and grape seeds, all of which merit further investigations either from the point of view of chemical alteration or from the detection of radiation history. A letter on these findings has been communicated to the Government Advisory Committee on novel and irradiated foods and a paper is currently being prepared for submission to a scientific journal.

General topics. A number of book chapters have been produced during the past year on general topics not related to particular techniques. Contributions on physical and chemical principles[1] and the characterization of iron complexes with soil organic matter[2] have been prepared for a book on "Iron in soils and clay minerals", of which Dr. B.A. Goodman is a co-editor. In the first of these chapters the nuclear and electronic properties of iron are discussed in order to provide an introduction to the principles needed to understand its chemical reactivity and results obtained by various spectroscopic methods. In the other contribution methods for investigating the reaction of iron with organic molecules are briefly reviewed along with a discussion of the relative importance of complexation and polymerization reactions for iron in soils. A review of the adsorption of metal ions and complexes on aluminosilicate minerals has been prepared for a special publication of the American Chemical Society[3]. In this work particular attention is given to work on the characterization of the nature of adsorbed species with emphasis on the contributions of spectroscopic methods to this important area of science. Mention is also made of the differences in nature of chemical reactions of adsorbed molecules compared to their free states and the potential value to be obtained from development of the chemistry of adsorbed species.

Computerisation and Automation

The interfacing of microcomputer systems with departmental analytical instrumentation has continued during the year with computerisation of an analogue IR spectrometer and a graphite furnace atomic absorption unit. The infrared laboratory makes extensive use of microcomputers for data

acquisition from dispersive and nondispersive spectrometers, instrument control, data manipulation and storage. As well as the research grade digital spectrometer, Perkin Elmer Model 580 B, a small analogue instrument, Perkin Elmer Model 577, is employed for routine studies and analysis. The analogue output recorder signal from this spectrometer has been interfaced to the Apple computers in the laboratory *via* an in-house designed, high-speed, 12-bit analogue-to-digital converter (Annual Report No. 55). The timing signals controlling the digitising function were obtained from a rotary optical encoder fitted to the grating drive shaft of the spectrometer. As well as digitising the IR spectral records, computer software was developed to format the data to allow current software to process, display and store the data. A detailed account of the interfacing and computer software has been prepared and accepted for publication[55]. A report on the use of error-free, data compression techniques for the storage of binary infrared data (Annual Report No. 55) has been accepted for publication[56].

Graphite furnace atomic absorption spectrometry is used extensively in the department for the determination of trace amounts of elements in analytical solutions. One instrument, a Pye-Unicam SP9 spectrometer, was purchased in 1984 and, fitted with an auto-sampler unit, is in routine automatic use. Although this instrument incorporates a video display screen and microprocesser module, the inherent facilities for processing the analytical data are severely limited. To permit more flexible data manipulation and formatting procedures, as well as providing a permanent record of the transient atomic absorption signals, the spectrometer has been interfaced to an Apple microcomputer. Analogue absorbance data is digitised and recorded during sample atomisation *via* an in-house constructed 12-bit analogue-to-digital computer. The absorption profiles, along with peak height and peak area data computed from the profiles, are stored in a random-access, data-base on floppy disks. Subsequent data processing facilities include calibration, by peak height or peak area results, using a moving 3-point quadratic fit algorithm employed by the instrument manufacturer. A report on the interfacing details and the Pascal processing software is in preparation.

The construction of the rapid-scanning microdensitometer (Annual Report No. 54 and 55) is complete and it will be employed for the interpretation of photographic plates from optical and mass spectrometers. The densitometer is linked to an Apricot computer system, for data processing, *via* an Apple microcomputer used for digitisation and data acquisition. Pascal data processing software is currently being designed and tested.

The increasing trend towards automation of analytical procedures in the department has prompted a study of automatic sample handling using random access autosampler units and continuous-flow analyser systems. A flow-injection analyser (FIA) unit has been purchased and, with a tri-axis autosampler (Annual Report No. 55), is being evaluated for use in the department. In collaboration with the manufacturers of the FIA instrument it is intended to study microprocessor control of the FIA/autosampler system, with an integrated detector unit, to provide the basis for more

intelligent analytical instrumentation. Such systems should increase the analytical precision and the rate of sample throughput. The analysis of aluminium by colorimetry, selenium by hydride generation/AAS and flame emission analyses will be examined for application with the new automated procedures.

Considerable interest is being shown in the use of computers to assist in technical and managerial decision making. This trend is partly due to the availability of low-cost expert systems designed to emulate the reasoning process of an expert in a particular field by reference to a model provided by the expert. One such commercial package, Micro-Expert, is currently being evaluated in the department. These studies will greatly assist in the design and operation of a laboratory information management system for future analytical requirements.

References

1. An introduction to physical and chemical principles. By B.A. Goodman. To appear in *Iron in Soils and Clay Minerals*. Eds. J.W. Stucki, B.A. Goodman and U. Schwertmann. D. Reidel, Dordrecht.
2. The characterization of iron complexes with soil organic matter. By B.A. Goodman. To appear in *Iron in Soils and Clay Minerals*. Eds. J.W. Stucki, B.A. Goodman and U. Schwertmann. D. Reidel, Dordrecht.
3. Adsorption of metal ions and complexes on aluminosilicate minerals. By B.A. Goodman. To appear in *Surface Processes in Aqueous Geochemistry*. Eds. J.A. Davis and K.F. Hayes, American Chemical Society, Special Publication.
4. Soil trace element maps. By M.L. Berrow. MISR Technical Note No. 4, Aberdeen, Macaulay Institute for Soil Research, 1986.
5. Soil data in the assessment of geochemical and environmental influences on trace element supply. By A.M. Ure. *Proc. 5th Int. Symp. on Trace Elements in Man and Animals*, Aberdeen, July 1984. Eds. C.F. Mills, I. Bremner and J.K. Chesters, Commonw, Agric. Bureaux, Farnham Royal, Slough, 906-909, 1985.
6. Relationships between trace element availability and the soils and geology of the Aberdeen area. By M.L. Berrow and A.M. Ure. *Proc. 5th Int. Symp. on Trace Elements in Man and Animals*, Aberdeen, July 1984. Eds. C.F. Mills, I. Bremner and J.K. Chesters, Commonw. Agric. Bureaux, Farnham Royal, Slough, 841-843, 1985.
7. Trace element mapping of Scottish soils. By M.L. Berrow and A.M. Ure. To appear in *Proc. 1st Int. Symp. on Geochemistry and Health*, London, 1985.
8. Lead in Scottish soils. By M.L. Berrow, W.M. Stein and A.M. Ure. To appear in *Proc. 4th European Meeting of The Society for Environmental Geochemistry and Health*, London, April, 1986.
9. Trace element distribution and mobilization in Scottish soils with particular reference to cobalt, copper and molybdenum. By M.L.

Berrow and A.M. Ure. *Environ. Geochem. and Health, 8*, 19-24, 1986.

10. Total chromium and nickel contents of Scottish soils. By M.L. Berrow and G.A. Reaves. *Geoderma, 37*, 15-27, 1986.
11. Occurrence and distribution of selenium in geological materials and soils. By M.L. Berrow and A.M. Ure. Chapter to appear in *Occurrence and Distribution of Selenium*. Ed., M. Ihnat, CRC Press Inc., Boca Raton, Fl., USA.
12. Location of trace elements in soil profiles: Total contents of particle-size separates. By M.L. Berrow and R.L. Mitchell. To appear in *Trans. Roy. Society of Edinburgh: Earth Sciences*.
13. Processes of mobilization and immobilization of iron in thin iron pan formation. By M.L. Berrow and B.A. Goodman. To appear in *Proc. North of England Soils Discussion Group*, 1985.
14. An overview of soil contamination problems. By M.L. Berrow. *Proc. Int. Conf. Chemicals in the Environment*. Eds. J.N. Lester, R. Perry and R.M. Sterritt, Lisbon, Selper Ltd., London, 543-552, 1986.
15. Cobalt, copper and molybdenum in Scottish soils. By M.L. Berrow. To appear in *Proceedings of the Nutrition Society*.
16. Design of a database for Scottish soils. By K.W.M. Brown, J.H. Gauld, B.F.L. Smith, D.C. Bain, J.C. Burridge and R.H.E. Inkson. To appear in *J. Soil Sci.*
17. Citation Classic No. 30, July 26, 1982, Page 182, in *Contemporary Classics in Plant, Animal and Environmental Sciences*, Ed. J.T. Barrett, ISI Press, Philadelphia, 371p.
18. The use of 2-ketogluconic acid in soil profile trace element studies. By M.L. Berrow and M.S. Davidson. *Trans. 13th Congr. Int. Soc. Soil Science*, Hamburg, Volume II, 239-240, 1986.
19. Assessment of soil cobalt and molybdenum status, from the simultaneous analysis of acetic acid an ammonium acetate extracts. By J.C. Burridge and A.H. Sinclair. To appear in *Irish J. Agric. Res.*
20. Determination of aluminium in soil extracts by carbon arc emission spectrometry after coprecipitation with iron using 8-hydroxyquinoline. By J.C. Burridge and I.J. Hewitt. *J. Anal. At. Spectrom. 1*, 41-44, 1986.
21. 2-Mercapto-4-propylacetanilide: an alternative to thionalide for precipitating lead from weak acid solution. By J.C. Burridge, I.J. Hewitt and H.A. Anderson. *The Analyst, 111*, 253-254, 1986.
22. A comparison of two soil-extraction procedures for the determination of EDTA-extractable copper and manganese. By J.C. Burridge and I.J. Hewitt. To appear in *Irish J. Agric. Res.*
23. Mobilisation of micronutrient cations into soil solution in the rooting zone of barley. By D.J. Linehan, A.H. Sinclair and M.C. Mitchell. Submitted to *Journal of Soil Science*.
24. The direct determination of cobalt in acetic acid extracts of soils by graphite furnace atomic absorption spectrometry. By M.C. Mitchell , M.L. Berrow and C.A. Shand. To appear in *Journal of Analytical Atomic Spectrometry*.

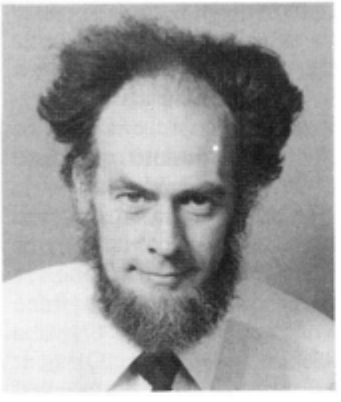
25. Graphite furnace atomic absorption determination of selenium in plant materials following combustion in a stream of oxygen. By C.A. Shand and A.M. Ure. To appear in *Journal of Analytical Atomic Spectrometry*.
26. Determination of cadmium in calcium chloride extracts of soils by atom-trapping atomic absorption spectrometry. By S.M. Fraser, A.M. Ure, M.C. Mitchell and T.S. West. *J. Anal. At. Spectrom.*, *1*, 19-21, 1986.
27. Atom-trapping atomic absorption spectrometric determination of some trace elements in soils, natural waters, seawater and bovine liver. By C.M. Lau, A.M. Ure and T.S. West. Submitted to *Analytica Chimica Acta*.
28. The development of a multi-sensor system using coated piezoelectric crystal detectors. By S.M. Fraser, T.E. Edwards and T.S. West. *The Analyst*, *111*, 1183-1188, 1986.
29. Estimation of percentage ground cover in potatoes by optical radiance measurements. By R.V. Birnie, P. Millard, M.J. Adams and G.G. Wright. To appear in *Research and Development in Chemistry*.
30. Portable radiometers for monitoring crop growth. By M.J. Adams, R.V. Birnie and G.G. Wright. Technical Note Number 9, MISR, 1986.
31. Nebulizers and spray chambers for inductively coupled plasma spectrometry. By B.L. Sharp. To appear in *Journal of Analytical Atomic Spectrometry*.
32. The versatile inductively coupled plasma. By L.C. Ebdon, S. Greenfield and B.L. Sharp. *Chemistry in Britain*, *22*, 123-130, 1985.
33. Optical, electron and x-ray spectrometry in soil analysis. By D.C. Bain, M.L. Berrow, W.J. McHardy, E. Paterson, J.D. Russell, B.L. Sharp, A.M. Ure and T.S. West. *Anal. Chim. Acta.*, *180*, 163-186, 1986.
34. Atomic spectrometry update — Environmental analysis. By M.S. Cresser, L.C. Ebdon, C.W. McLeod and J.C. Burridge. *J. Anal. At. Spectrom. 1*, 1R-17R, 1986.
35. Atomic spectrometry update — Atomization and excitation. By B.L. Sharp, N.W. Barnett, J.C. Burridge and J.M. Ottaway. *J. Anal. At. Spectrom. 1*, 121R, 1986.
36. The spark-source mass spectrometric determination of the trace element composition of human foetal liver. By C.A. Shand, P.J. Aggett and A.M. Ure. *Proc. 5th Int. Symp. Trace Elements in Man and Animals*, Aberdeen, July 1984. Eds. C.F. Mills, I. Bremner and J.K. Chesters, Commonw. Agric. Bureaux, Farnham Royal, Slough, 642-645, 1985.
37. Multi-element analysis of liver and kidney samples by spark-source mass spectrometry. By J.R. Bacon. *Advances in Mass Spectrometry*, Vol. 10, 1986.
38. Inorganic trace analysis by mass spectrometry. By A.M. Ure and J.R. Bacon, Chapter to appear in *Applications of Mass Spectrometry in Food Science*, Ed. J. Gilbert, Elsevier, Amsterdam.

39. Sources and speciation of aluminium and silicon in natural waters. By V.C. Farmer. *Silicon Biochemistry*, Ciba Foundation Symposium, No. 121, 1986.
40. The role of inorganic species in the transport of aluminium species in podzols. By V.C. Farmer. Submitted to *Science du Sol.*
41. Synthetic and natural allophane and imogolite: a synergistic relationship. By V.C. Farmer. To appear in *Trans. 13th Congr. Int. Soc. Soil Science*, Hamburg.
42. The structure and genesis of allophanes and imogolite: their distribution in non-volcanic soils. By V.C. Farmer and J.D. Russell. To appear in *Proc. NATO ASW Soil Colloids and their Association in Soil Aggregates*, Eds, M.B. Hayes, M.F.L. DeBoot, A. Herbillon, D. Reidel, Dordrecht.
43. Compositional and structural variations in the size fractions of a sedimentary and a hydrothermal kaolin. By G. Lombardi, J.D. Russell and W.D. Keller. To appear in*Clays and Clay Minerals.*
44. Infrared spectroscopy of inorganic compounds. By J.D. Russell. To appear in *Laboratory Methods in Infrared Spectroscopy*. Ed. H. Willis, Wiley, New York.
45. The effect of pH on the chemistry of manganese, iron and aluminium oxides. By V.C. Farmer, B.A. Goodman and E. Paterson. To appear in *Trans. 13th Cong. Int. Soc. Soil Science*, Hamburg.
46. On the nature of the calcium carbonate in the exoskeleton of the woodlouse. *Oniscus asellus L.* By S. Wood and J.D. Russell. To appear in *Crustaceana.*
47. Polymaleic acid as a humic substance model. I. Evidence from spectroscopic studies and chemical degradation. By H.A. Anderson, A.R. Fraser, A. Hepburn, J.D. Russell, D.I. Welch and M.A. Wilson. To appear in *J. Soil Science.*
48. The aromaticity of soil fulvic acid: response to comments by M. Schnitzer. By V.C. Farmer. *Nature, 313*, 658, 1985.
49. The use of Mössbauer spectroscopy in the study of colloidal materials. By B.A. Goodman. To appear in *Proc. NATO A.S.W. Soil Colloids and their Association in Soil Aggregates*. Eds. M.H.B. Hayes, M.F.L. DeBoot and A. Herbillon, D. Reidel, Dordrecht.
50. A Mössbauer effect study of the mineral Macaulayite. By D.E. Sawcer, B.A. Goodman, J.D. Russell and M.F. Thomas. Submitted to *Phys. Chem. Minerals.*
51. The transformation of ferrihydrite during the concentration of crystalline iron oxides by treatment with alkali. By B.A. Goodman, M.L. Berrow and J.D. Russell. Submitted to *J. Soil Science.*
52. Characterization of iron fulvic acid complexes using Mössbauer and EPR spectroscopy. By B.A. Goodman and M.V. Cheshire. To appear in *Sci. Total Environ.*
53. Oxygen-induced free radical in wheat roots. By B.A. Goodman, D.B. McPhail and D.J. Linehan. To appear in *Free Radical Research Commun.*

54. An evaluation of EPR measurements of the organic free radical content of individual seeds in the non-destructive testing of seed viability. By H.A. Hepburn, B.A. Goodman, D.B. McPhail, S. Matthews and A.A. Powell. To appear in *J. Exp. Botany*.
55. Interfacing an analogue IR spectrometer to a microcomputer. By M.J. Adams and G.J. Ewen. To appear in *Talanta*.
56. Error-free storage compression of binary-coded infrared spectra. By M.J. Adams and I. Black. To appear in *Analytica Chimica Acta*.

4. SOIL ORGANIC CHEMISTRY

M.V. CHESHIRE



The importance of processes involving organic chemistry in the maintainance of soil fertility cannot be over emphasised. Organic substances in soil are probably transformed by both diagenetic and abiotic events, but the biochemical changes predominate, even though they are sometimes very slow in the soil medium in comparison with similar processes in living cells.

Much of the work performed on soil organic matter is necessarily carried out by procedures adapted from organic chemistry, whereas a more appropriate approach to understanding the observations made would seem to be that of biochemistry. Many functional aspects of organic matter in soil such as nutrient cycling thus depend on substances in a continual state of flux. The work of the department covers many facets of this vital soil component.

Nitrogen

Almost all soil organic nitrogen can be recovered in easily characterizable forms from fresh soils by chemical hydrolysis, whereas with dried soils a significant proportion of the nitrogen in the humic substances is in an unknown form. It has been established that when air-dried sieved arable top soil is returned to field conditions by remoistening and incubating for two weeks, the so-called unknown fraction of the nitrogen in isolated humic substances is insignificant. (Annual Report No. 55, 1985). This study is now being extended to include forest soils and peats. These findings show that sample handling techniques which minimize drying and oxidation will need to be developed for future investigations of nitrogen cycling. 4019

In collaboration with the Department of Soil Fertility, an analysis is being made of the ^{15} N contents of humic substances isolated from soil cores taken from under a potato crop receiving ^{15}N-labelled nitrate fertilizer in a large-scale field experiment within the Institute grounds. This involves the meticulous application of a scaled down version of the extraction and fractionation procedure recommended by the International Humic Substances Society using 2 g soil samples in place of the usual 1 kg quantities.

Analysis of the isolated humic, fulvic and hydrophilic acid fractions shows, as expected, a very low level of incorporation of label into humic substances in the early stages of the experiment. 4019, 7039

The incorporation of ^{15}N into soil organic matter by nitrogen fertilization of successive crops of fescue, which are subsequently composted in the soil,

has continued (Annual Report No. 54, 1984). The subsoil soils used in this experiment show minimal increases in nitrogen and carbon contents. After characterization of the ^{15}N components, the soils will be used to determine the net mineralization of the organic N and its uptake by a grass crop during the coming season. 4019

A paper describing the chemical interaction of glycine with reactive substances in peat using ^{13}C and ^{15} N NMR spectroscopy has now been published[1]. The study involved the incubation of ^{15}N labelled glycine in γ-irradiated, autoclaved or untreated peat. Resonances were observed corresponding to amine, secondary amide, pyrrole type nitrogen and melanoidins, indicating the presence of Maillard reaction products.

In the non-sterile peat incubations the presence of aliphatic amines and secondary amide linkages could be the result of microbiological activity or chemical reaction whereas in the sterile peat, chemical reactions alone are considered to be responsible. This work has involved collaboration between the Departments of Peat and Forest Soils, Microbiology, Soil Organic Chemistry and the Chemistry and Biology Research Institute, Ottawa, Canada. Studies are continuing on the distribution of ^{15} N labelled substrates amongst different particle size fractions after incubation in peat. 2055, 4020, 6027

Investigations are being carried out into the optimization of the determination of imino acids by using an oxidation-reduction sequence prior to derivatization with ortho-phthalaldehyde and reverse phase chromatography. Preliminary work has shown that this entire sequence of sample manipulation can be automated, so aiding the routine amino acid analysis service. 4904

Humic Substances

In collaboration with the Department of Soil Survey, a paper[2] has been submitted for publication concerning the use of a podzolization index based upon the inter-relationships between acid-soluble organic matter, aluminium and phosphate. The results have been contrasted with those derived from the application of three different sets of chemical criteria defining spodic horizons applied by the Soil Survey of England and Wales, the Canadian Soil Survey and the U.S. Department of Agriculture. The criteria in these latter three are over-restrictive in their demands on specific chemical or physical soil parameters, whereas the criteria in the former, although somewhat arbitrary in the preliminary form described in the submitted paper, are sufficiently flexible to be applied to a wide range of soils. The examples discussed include brown podzolic soils, a class known to be difficult to define on morphological evidence. Since this work, the index method has been amplified by quantitative measurements of dissolved organic carbon in soil extracts, replacing organic matter measurements based solely upon visible light absorbance. 4021

The podzolization index has been used to confirm the classification of a series of peaty podzols and peaty fragogleys from Sutherland in terms of the

degree of compaction or cementing of the lower B horizons by changes in acid-soluble phosphate.

The index has also been used in collaborative work with the Department of Geography in the University of Strathclyde to test whether podzolization can be detected by chemical analysis prior to its observation in the field. The site being examined is in woodland on Linhope series, Ettrick Association soil, where Silver Birch trees have been replaced with conifers. 4021

In collaboration with the Scottish Crop Research Institute, phenolic acids have been determined in extracts of soils from a field affected by carrot cavity spot. Although it has been established that the disease is the direct result of a fungal infection, the lesions that develop could be caused through the agency of salicylic acid, an acid previously detected in soil extracts from affected areas within certain fields. The earlier work was repeated this year using soils from the same Norfolk field which was again exhibiting the disease. Levels of salicylic acid were found in aqueous soil extracts which were sufficient to cause lesion and the distribution of high values correlated well with the pattern of occurrence of the disease within the field.

Attempts to relate the occurrence of salicylic acid to the possible aerobic or anaerobic decomposition of the iso-coumarin mellein, which occurs in carrots with cavity spot, were unsuccessful, with no phenolic acid being detected in extracts from soil incubations amended with mellein. 4021

Several papers concerning the properties of humic substances and methods for their analysis have been published during the year[3,4,5,6].

4020, 4021, 4064

Soil Carbohydrate

Studies on the rate of decomposition of plant tissues such as straw and grass leaf are continuing in collaboration with the Department of Statistics. Data obtained by measuring the residual carbohydrate components of straw and grass leaf over incubation periods of time up to five years have been used to test various mathematical models based on exponential functions.

Three types of function have been examined in particular, simple multicomponent exponential expressions and single term exponential-type expressions devised by Janssen and by Weibull. In addition, an expression using a modification of a two-part exponential expression by the substitution of one term by the Weibull expression has been tested.

Apart from the Weibull expression on its own, the models generally gave a good fit to the data, with no significant differences being observed between them. One exception to this was with the application of the Janssen-type expression to cellulose decomposition in grass, for which no constants could be found which would allow a solution.

The implications from this study are that the materials decomposing are changing with time, even where they are chemically well defined substances. This idea is expressed in the Janssen-type function where the rate of decomposition is dependent on time, the equation incorporating a term

representing the apparent initial age. The Weibull-type function provides a better way of expressing an effect of time, but this, in a single term function, gave a significantly poorer fit to the data. The change with time in a substrate is considered to be the result of increasing inaccessibility caused by clay or mineral matter adsorption, the accumulation of dead microorganisms or the blocking of sites by inactive enzymes. This will result in an increased difficulty of penetration of active enzymes.

This work has relevance to the disposal of straw by incorporation in soil. The results of this study have been presented at the XIII congress of the International Society of Soil Science[7] and a full paper has been submitted for publication[8]. 4020, 6027, 8057, 8059

Quite some time ago it was pointed out that the pattern of decomposition of substrates such as straw in soil was similar to that in the rumen. Recent studies in the rumen have successfully involved the use of reflectance infrared spectroscopy to follow the changes in the components of straw in terms of the straw surface. Such a technique may be capable of revealing similar changes in soil and this is being investigated in collaboration with the Department of Spectrochemistry in parallel with chemical studies. 3017, 4020

Studies in collaboration with the Department of Microbiology have continued on the changes both qualitative and quantitative brought about by various soil invertebrates on the decomposition of plant residues in soil.

In addition to crane-fly larvae (*Tipula paladusa*), and earthworms (*Allobophora* and *Lumbricus spp.*) experiments have been conducted with woodlice (*Porcellio scaber*) to test their effect on the decomposition of ^{14}C-labelled grass or *Lemna gibba* in soil. In the first few weeks of incubation the invertebrates increased the rate of decomposition of the substrates, but their effects are less apparent over a longer period of several months. Nevertheless, differences were still observed even after a year.

Results indicating the digestive capability of the crane-fly larvae, *Tipula paladusa* have now been accepted for publication[9]. 4020, 6027

Experiments have continued on the effects of monocultures of organisms on soil aggregation. Organisms were chosen which produce extracellular polysaccharides with a range of uronic acid contents from 0 to 70%. The greatest aggregating effects have been observed using A horizon soil, whereas with C horizon soil they were negligible, despite a good growth of the organism. C horizons were used because, lacking a good structure initially, it was thought that any aggregating effects would be more obvious. The difference between A and C horizons in relation to the agggregating effects of monocultures, may relate to the presence of more humified organic matter in the former. Alternative soil preparations have involved A horizon soil treated with sodium periodate to remove specifically much of the soil carbohydrate, and C horizon supplemented with adsorbed humic acid. The effects observed with these preparations have been slight or accountable to the inorganic and organic media supplements supplied to enable the microorganisms to flourish. The initial physical state of the soil preparation appears to be crucial, however, even in incubations lasting several months.

A preliminary report on this study has been presented at the XIV International Congress of Microbiology[10]. 4020, 6027

The presence or absence of an ionic site in polysaccharide will determine the nature of its association with soil mineral matter. Neutral polymers are considered to be strongly adsorbed by clay surfaces whereas, because of like charges, negatively charged polymers would either be repelled or react through metal ion bridges. It was therefore of interest to study the distribution of charge in extracted soil polysaccharides by means of isoelectric focussing. Using a dextran gel-ampholite system, polymers were found with pI values over the range 1.9 to 9 showing the presence of positively and negatively charged and neutral species. There was a preponderance of material which was negatively charged. Part of this charge could be accounted for as uronic acid components, but the most acidic fractions gave less uronic acid and more aliphatic acids on hydrolysis than some of the less acidic ones. Reseparation of isolated fractions indicated that diffusion and dissociation/association reactions occurred as well as strong adsorption to the gel bed. Electrofocussing would appear to be of limited value as a means of fractionating polysaccharide. A paper describing these findings is awaiting publication[11]. 4020

Soil enzymes

The effects of different levels of nitrogen fertilizer applied to barley and grass crops on soil enzyme activities have been measured in field plots during the 1985 and 1986 growing seasons. Changes in enzyme activities were more closely related to the presence of growing plants than to nitrogen supply. Under barley the activities of amylase, cellulase, dehydrogenase and phosphatase were enhanced in comparison with the activities in fallow plots. Adding inorganic N fertilizer only marginally enhanced the activities of the enzymes throughout the growing season, even though it considerably enhanced plant growth. A similar effect was observed for soil enzymes under grass with the exception of cellulase which remained constant in all treatments. 4064

Enzyme-Clay Interactions

To elucidate mechanisms involved in influencing enzyme activities in soil, studies have continued, in collaboration with the Department of Mineral Soils, on the adsorption of cellulase on montmorillonite. As the pH of the medium is lowered, greater adsorption occurs and there is a decrease in enzyme activity. X-ray diffraction measurements have shown that the interlayer space occupied by the enzyme is about 15 A (basal spacing 24.6) at pH 3.5 and 10 A (basal spacing 19.6 A) at pH 5.5. The composition of the buffer also determines how much adsorption occurs. Sodium acetate/acetic acid mixtures allow more adsorption than sodium phosphate/citric acid ones. This observation has relevance to the measurement of soil enzymes because the choice of buffer influences the activity.

At pH 3.5 more than 90 per cent of the final total adsorption of the enzyme occurs within one minute of its addition to a buffered suspension of the clay. De-sorption has never been observed at this pH, even when the mixture is sonicated. After adsorption at pH 5.5, sonication released up to 20 per cent of the enzyme.

A hyperbolic relationship between enzyme concentration and adsorption by montmorillonite has been observed for both bovine serum albumin and cellulase. Only 35-40 per cent of the total enzyme present is adsorbed.

Albumin complexes with the clay more readily than does cellulase, reaching maximum saturation at an enzyme : clay ratio of 0.1:1. At a ratio of 4:1 the first order basal spacing is about 50 A, considerably greater than the 24.6 A obtained for cellulase.

Previous reports in the literature on bovine serum albumin-montmorillonite complexes give a basal spacing of only 25 A which the present studies have shown to be the second order values of the true 50 A first order spacing. 4064

Metal-Organic Matter Interactions

Studies using Mossbauer spectroscopy on the interaction of iron and humic substances have continued in collaboration with the Department of Spectrochemistry. The range of fulvic acid : iron ratios has been extended and interpretation of the reaction facilitated by parallel examination using electron paramagnetic resonance spectroscopy. Fulvic acids have the capacity to form small amounts of mononuclear complexes of iron over a wide range of pH. The substantial reduction of iron that occurs at low pH appears to involve polymeric iron species. Low temperature Mossbauer experiments are currently being undertaken to characterize some of the unidentified Fe III components.

A paper describing these results was presented to a meeting of the International Humic Substances Society[12].

A review paper on the involvement of organo-mineral complexes in pedogenesis has been published during the year[13]. 3808, 4808

Micronutrients in Soil Solutions

Work on the mobilization of the micronutrients Cu, Zn, Mn and Co into the soil solution of the rooting zone of plants has continued in collaboration with the Department of Soil Fertility. The investigation has been extended to include field-sown winter wheat and oil seed rape. Maximum mobilization in the rooting zones of autumn sown crops corresponded to the period of maximum growth in early spring (Fig. 4.1) as was the case for autumn sown barley (Annual Report No. 55, 1985) and contrasts with the later period of mobilization previously observed for spring sown barley crops. A paper describing some of this work has been accepted for publication[14]. Field experiments have indicated that soils from different locations exhibit very different levels of micronutrient mobilization. Experiments carried out in the glasshouse, where non-soil variables are

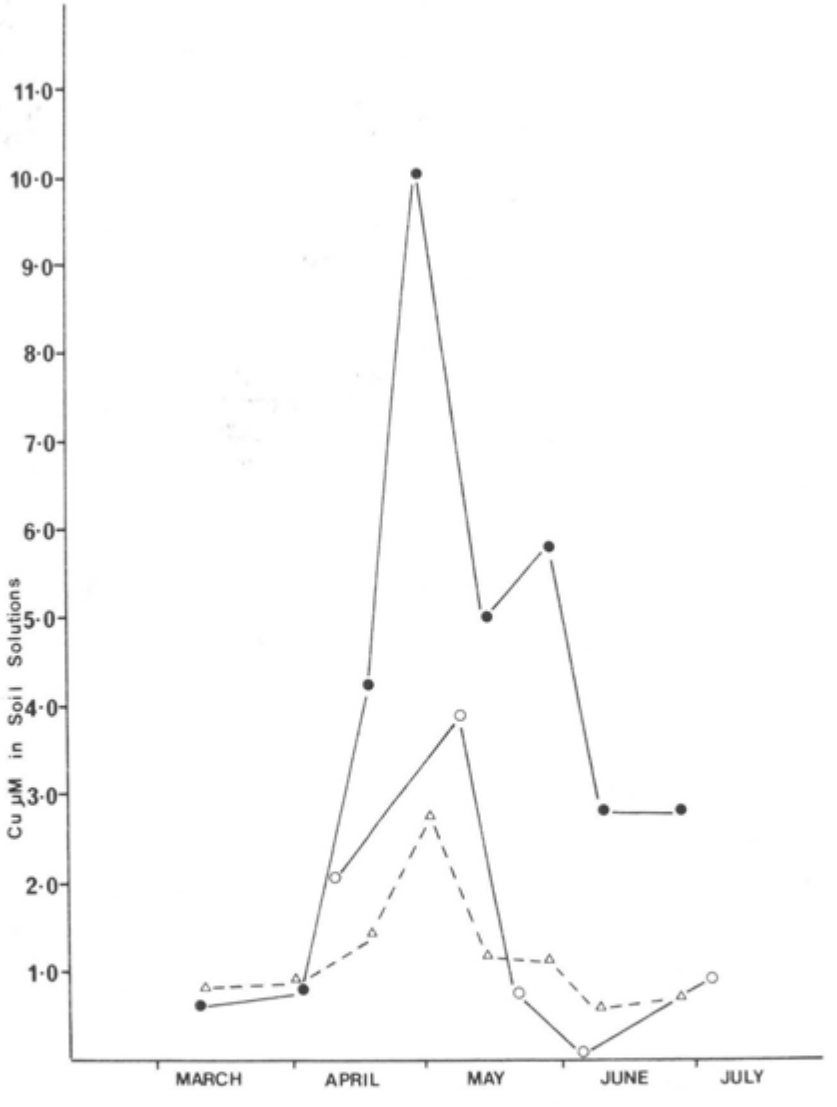


Fig. 4.1 Copper mobilization in the rooting zones of autumn sown crops. ●—● oil seed rape, ○—○ wheat, △—△ barley.

minimized, have provided some confirmatory evidence of such intersoil differences which established soil testing procedures have proved ineffective in revealing.

The investigations of micronutrient concentrations in rooting zone soil solutions has been extended to the potato crop as part of an investigation by the North of Scotland College of Agriculture on the use of chelated manganese and zinc in the control of powdery scab disease. The soil

solutions analyses showed that the use of these products did not significantly increase Zn or Mn concentrations in the soil solution. They also showed that at the main experimental site there was very substantial mobilization of these elements into the rooting zone of the potato. Such high levels of naturally mobilized Zn and Mn might explain the relatively low incidence of powdery scab observed at that site. 4803, 7041

Surface Water Acidification Programme

In July Dr D.I. Welch was appointed to the staff of the Department on a three year term contract funded by the Royal Society Surface Water Acidification Programme to work on the identification and role of organic anions in surface water acidification.

Modification of the microwave plasma spectrometer system has enabled the dissolved organic carbon (DOC) contents of waters and extracts to be determined readily. The spectrometer is interfaced with a flow analyser which incorporates a UV reactor. Samples are mixed with persulphate ion and are subjected to intense UV irradiation in a quartz coil, resulting in the degradation of organic compounds into carbon dioxide and other oxides. This reaction is carried out in an argon atmosphere; after washing to remove halogens and nitrogen oxides, and drying, the gas phase is passed into an argon plasma at atmospheric pressure. Measurement of the carbon dioxide emission line at 247.8 nm allows an estimation of the DOC of samples at a rate of 20 per hour, a rate comparable with most commercial instruments.

The detection system has also been used to measure carbon dioxide in the head-space above soil incubations. In this mode it is highly efficient, requiring only 20 μl samples and making measurements every 10 seconds.

The main emphasis of the work has been on the analysis of the SWAP survey and plot soils, using the podzolization index analytical scheme. The interaction between soil organic matter and aluminium is being studied using additional soil samples taken from transect lines at the Loch Chon and Allt a' Mharcaidh sites. The analyses of the survey and plot soils had shown that, on a dry weight basis, there was an apparent increase in the acid-soluble aluminium content of the organic-rich soils with depth, and that this feature was especially evident in the peats. When the data are transformed to a weight per field-moist volume basis, the organic-rich soils record lower contents of acid-soluble aluminium than the mineral soils. Attempts are being made to characterize the exchange complex associated with aluminium in the organic-rich soils.

A study of the soluble organic anions in the water inputs and outputs at the field sites is being made using selective adsorption on disposable solid phase columns which allow a five hundred-fold increase in concentration. In addition to the carboxylic acids commonly found in soil waters, several unknown compounds have been isolated and are being characterized. 4809

Ochre in field drains

Collaboration with the North of Scotland College of Agriculture and the Department of Soil Survey has continued on investigations into the problem

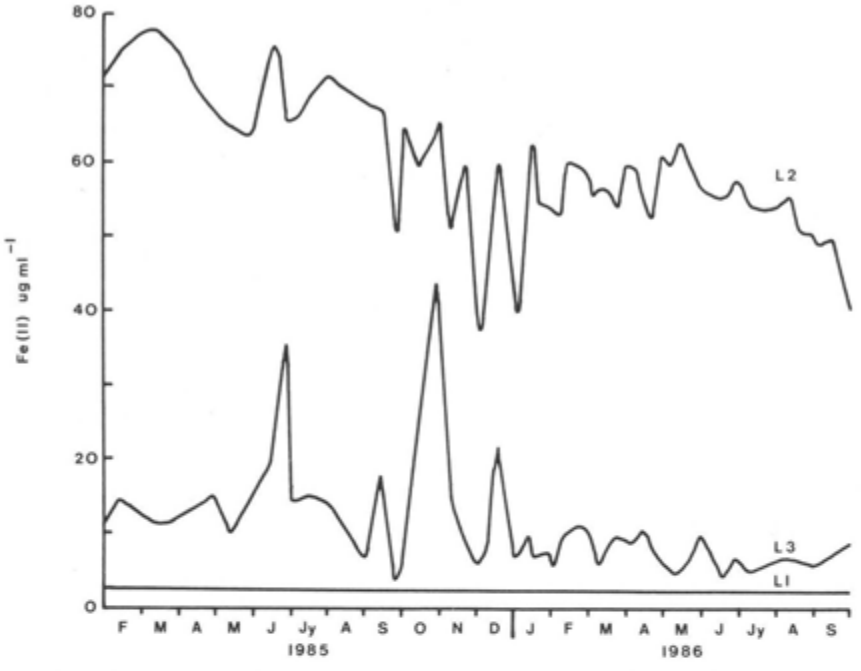


Fig. 4.2 Weekly changes in the concentration of ferrous iron in three drainage lines from a field with a severe ochre problem.

of iron ochre deposition in field drains. Prediction of the seriousness of an iron ochre problem may be made on the basis of the concentration of ferrous iron in the drainage water in relation to pH. To obtain more information about the variation of ferrous iron concentration throughout the year, drainage lines have been regularly sampled on a local farm with an extensive ochre problem.

Although the amounts of iron being released in drainage water were found to vary considerably during the year, there was some relationship between flow rate and the amount of soluble ferrous iron, so that the concentration tended to remain constant (Fig. 4.2).

Laboratory experiments have shown that most of the ochre precipitation at this site is the result of biological activity. It may be prevented by Cu^{2+} ions, metabolic inhibitors such as cycloheximide or chelating tannins.

Two coniferous bark infill experiments at Elgin and Campbeltown continue to give satisfactory results. At both sites the bark was mixed with gravel to maintain a greater drain line efficiency. After two years in the field there was no appreciable decomposition of the bark. It is considered that this method of bark application is suitable where there is a temporary ochre problem which will cease after a few years.

At two other sites in Campbeltown, experiments continue on the use of renewable sacks of bark held in plastic chambers spaced out along the drainage line. 4801, 9801

Removal of Copper from Industrial Wastes

Wastes and by-products of the whisky industry, some of which may be processed for use in agriculture, contain appreciable quantities of copper. It is becoming necessary to devise economic ways of lowering their copper contents to meet the requirements of an EEC directive on the disposal of heavy metals in sewage sludges and other discharged wastes.

A project has commenced with the aim of identifying the forms of copper present in the by-products and finding suitable methods of treatment. Preliminary work has indicated that spent lees, which contains up to 90 per cent of its copper in an ionic form, is relatively easy to treat by adsorption of the copper onto materials such as ion exchange resins or coniferous bark or by precipitation on raising the pH. A more difficult problem is presented by the pot ale, where more than 90 per cent of the copper appears to be present in covalently bound forms. 4068

Labelling of Plant Material

Work has continued in collaboration with the Department of Plant Physiology on establishing conditions for optimizing the yield and specific activity of uniformly ^{14}C-labelled *Lemna gibba* L. when grown in solutions of ^{14}C glucose under axenic conditions. The material is intended for use in soil incubation experiments.

Much of the Institute's previous work on *Lemna* used a nutrient growth medium containing nitrogen as both nitrate and ammonium. In this medium *L. gibba* appeared similar to *L. minor* in exhibiting no gibbosity (a convex ventral surface). It has now been shown that the gibbosity of *L. gibba* depends on the form in which nitrogen is supplied. In the absence of ammonium nitrogen in dilute nitrate solutions *L. gibba* shows gibbosity, provided that iron is readily available as ferric EDTA, whereas *L. minor* does not, whatever the form or concentration of nitrogen.

The choice of the iron chelating agent is also crucial; some, such as citrate, do not produce gibbous plants. It is interesting that humic and fulvic acids from various arable soils, peat and dopplerite all result in the formation of gibbous fronds.

In contrast to the nitrogen supply, carbon has no effect on gibbosity in *L. gibba*. Increasing the atmosphere CO_2 supply up to one per cent enhances the growth of *L. gibba* and *L. minor* in the light. An increase in glucose concentration also enhances the yield of both *Lemna* species, but at higher glucose concentrations (1 — 2 per cent) ammonium is a requirement for growth in addition to nitrate.

In the absence of light there is almost no growth, but a pulse of white light for as little as 15 minutes every three days is sufficient to allow rapid growth to occur. After this treatment, as in continuous light, the growth of *Lemna* is related to the glucose concentration with the difference that there is no increase in the number of green fronds, only in yellow fronds. This suggests that the light is needed to activate the phytochrome system and that photosynthesis is not necessary for the growth of fronds in the presence of glucose.

The chemical composition of the two *Lemna* species has been examined by infrared spectroscopy, in collaboration with the Department of Spectrochemistry. Unlike many higher plants *Lemna* appear to contain no detectable lignic or aromatic constitutents, the major components being protein and polysaccharides. In *Lemna gibba* there is consistently more protein relative to polysaccharide than in *L. minor*. No chemical distinction could be made between the gibbous and non gibbous forms of *L. gibba* .

3017, 4020, 4064

Environmental Effects on Seedling Growth

Experiments designed to elucidate the effect of environmental forces on seedling growth have directed attention to the role of the epidermis in the regulation of growth. Seedlings placed horizontal in a solution of auxin do not exhibit the growth differential between upper and lower surfaces which normally results in curvature, whereas seedlings similarly immersed in aqueous solutions of other growth regulators, such as gibberellic acid, exhibit the expected geo-response. This suggests that, in accordance with the classical Cholodny-Went theory, the establishment of an auxin gradient across the hypocotyl is an essential prerequisite for curvature. However, if the hypocotyl is split longitudinally and immersed in a solution of auxin, differential growth is established between the outer (epidermal) and inner (cut) surfaces of the two halves, the epidermal surface outgrowing the cut surface with the result that both halves begin to curve inwards (Fig. 4.3). This differential growth response is a consequence of differing sensitivities of the outer and inner tissues to auxin and is in accordance with the view that the epidermal cells function as target tissue for auxin. When both outer and inner hypocotyl tissues are exposed to auxin, the hypocotyl is incapable of responding to gravity and, irrespective of orientation, both halves of the hypocotyl begin to coil inwards. (Fig. 4.4). This response appears to be unique to auxin and a new theory to account for tropic curvature has been derived from it.

Briefly, this theory views the differential growth response associated with curvature as a consequence of a lateral transport of auxin between epidermal cells whose growth is stimulated by auxin, and sub-epidermal cells whose growth is inhibited by auxin. (Fig. 4.5). The innovative elements in this model of geocurvature, distinguishing it from trans-organ hypotheses such as that of Cholodny-Went, are that there is a differential auxin sensitivity between distinct tissues which lie adjacent one to the other so that auxin redistribution occurs between adjoining cells. This concept of close-range redistribution makes irrelevant questions as to whether auxin can be transported in sufficient quantity and at sufficient speed from one surface to the other to bring about curvature. Transport from one layer of cells to an adjacent layer having a different auxin sensitivity could, of itself, bring about curvature, arresting the growth of the upper surface and promoting the growth of the lower surface (Fig. 4.5).

This auxin transport between adjoining tissues having differing sensitivities to the growth regulator, can also account for the downward

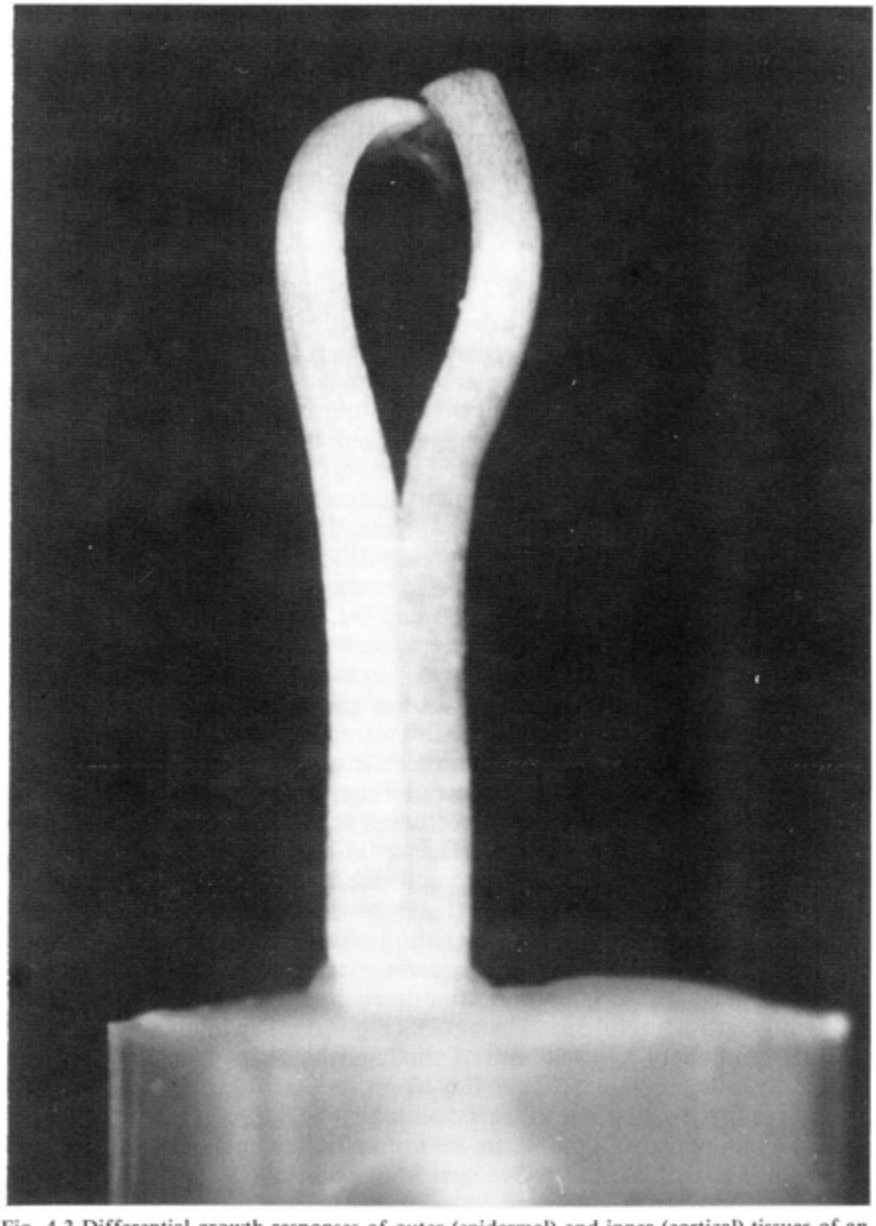


Fig. 4.3 Differential growth responses of outer (epidermal) and inner (cortical) tissues of an etiolated sunflower hypocotyl split longitudinally and immersed in lO μM auxin solution.

geocurvature of roots if it is assumed that the transition from shoot to root involves the spatial transposition of the auxin-positive and auxin-negative tissues (Fig. 4.6). That such a transposition occurs, is supported by the

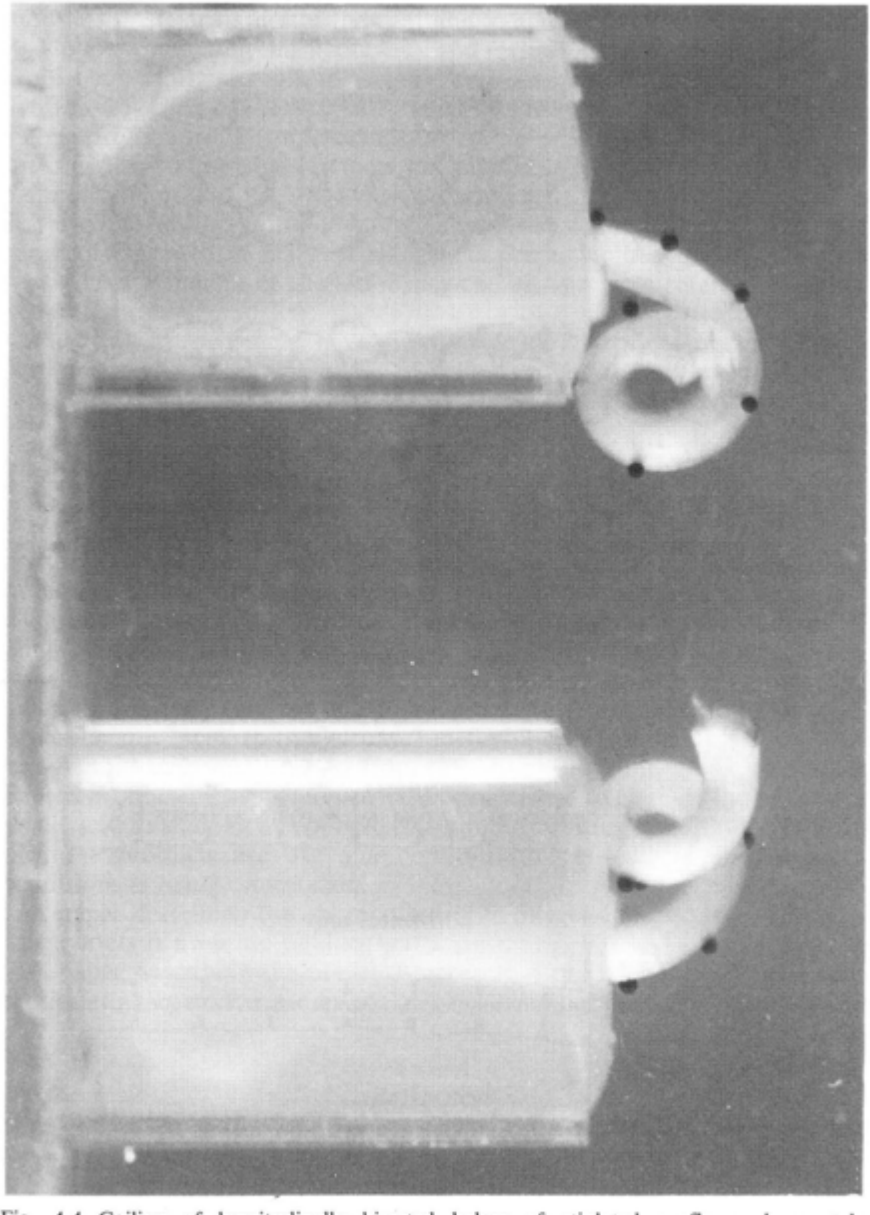


Fig. 4.4 Coiling of longitudinally bisected halves of etiolated sunflower hypocotyls horizontally positioned in a solution of lO μM auxin. Note the lack of any gravitational response, both upper and lower halves bending away from the epidermal surface.

morphological differences between root and shoot, the inhibition of the growth of intact roots by auxin concentrations which are without effect on

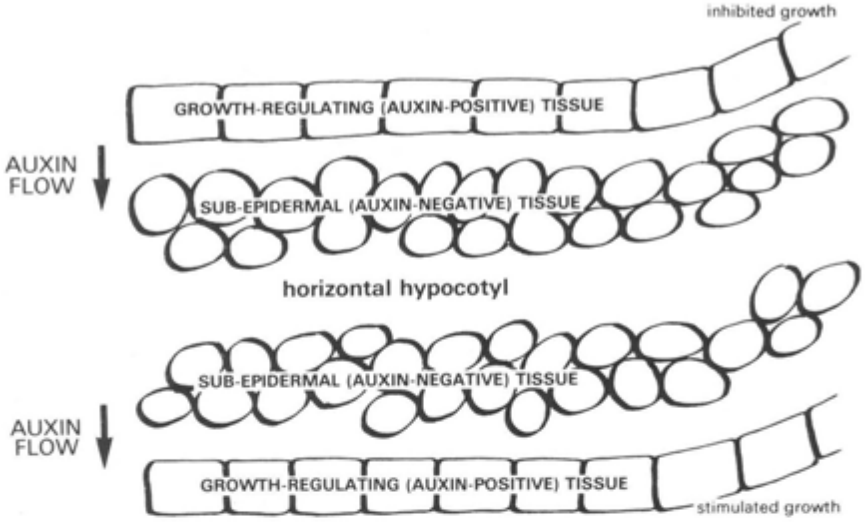


Fig. 4.5 Diagrammatic representation of growth rate changes caused by auxin flow between differentially-sensitive tissues in a horizontal hypocotyl.

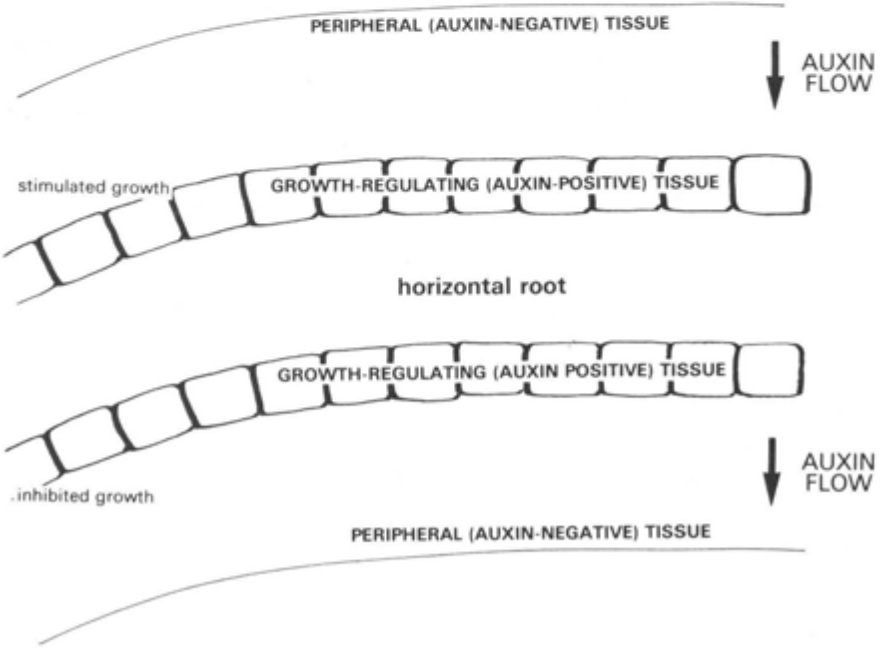


Fig. 4.6 Diagrammatic representation of growth rate changes caused by auxin flow between differentially-sensitive tissues in a horizontal root.

intact shoots, and the evidence that auxin tends to be present in higher amounts in stelar tissues of the root and in epidermal tissues of the shoot.

A paper presenting this hypothesis and reviewing the role of hormones in tropic curvature was given at the Tenth Long Ashton Symposium on *Hormone Action in Plant Development* and will appear as a chapter in the published Symposium proceedings[15].

A paper on the measurement of relative elemental elongation rates (Annual Report No. 55, 1985) has been accepted for publication[16]. So also has a paper dealing with video-image analysis of phytochrome-controlled mesocotyl growth in maize seedlings[17], a project jointly undertaken with Mrs Avital Yahalom of the University of Tel Aviv, and referred to in last year's Report.

Further improvements have been made to the video-image analysis equipment with the incorporation of better facilities for editing video-tape. 4053

Other Work

In collaboration with the Department of Microbiology, extracts of culture filtrates from *Penicillium echinultum* have been fractionated in order to isolate antibiotic compounds. Initially, the organism gave rise to a compound identified at 5-hydroxymaltol (2-methyl-3,5-dihydroxy-pyran-4-one), which has previously been identified in certain bacteria, but is better known as a carbohydrate dehydration product arising in 'browning' reactions. Later cultures gave none of this product, but instead, mycophenolic acid (6-(4-hydroxy-7-methyl-3-oxo-5-phthalanyl)-4-methyl-hex-4-enoic acid) was isolated from the culture medium, along with other related products. The difference has been ascribed to changes in the culture media and to shaking as opposed to stationary culture conditions. As both of these products are of value, optimization of culture and recovery conditions is being undertaken. 4021, 6026

A paper describing the observation of an oxygen-induced free radical in wheat roots is awaiting publication[18]. 3803, 4803

A paper describing the use of 2-mercapto-4-propylacetanilide as a lead precipitating agent for use in analysis has been published[19]. 3010, 4021

References

1. Fate of [^{15}N] glycine in peat as determined by ^{13}C and ^{15}N CP-MAS NMR Spectroscopy. By L.M. Benzing-Purdie, M.V. Cheshire, B.L. Williams, G.P. Sparling, C.I. Ratcliffe, and J.A. Ripmeester. *Journal of Agricultural and Food Chemistry* 34, 170-176, 1986.
2. Features of podozisation in soils from two undisturbed sites in Scotland. By J.H. Gauld, A. Hepburn and H.A. Anderson. Submitted to *Journal of Soil Science*.
3. Variation of humic substances within peat profiles. By H. Anderson and A. Hepburn. In *Peat and Water : Aspects of Water Retention and*

Dewatering in Peat. Ed C.H. Fuchsman Elsevier Applied Science Publishers, London 1986. pp 147-194.

4. Biochemical and other soil analyses. By H.A. Anderson and A. Hepburn. In The Pit Alignment at Eskbank Nurseries. By John Barber. *Proceedings of the Prehistoric Society*, 57, 149-166. 1985.
5. Electron paramagnetic resonance characteristics of the humic acids from a podzol. By M.V. Cheshire, B.A. Goodman, D.B. McPhail and G.P. Sparling. *Organic Geochemistry*, 8, 427-440, 1985.
6. Effect of humic substances on metabolic processes in plants. By D. Vaughan. Proceedings of the symposium '*Contribution of humic substances to the soil and their action on plant growth*. 1986. pp182-213.
7. Decomposition of the carbohydrates of ryegrass and straw in soil. By M.V. Cheshire, R.H.E. Inkson and C.M. Mundie. Volume II Transactions XIII Congress of the International Society of Soil Science. pp563-564, 1986.
8. Studies on the rate of decomposition of plant residues in soil by following the changes in sugar components. By M.V. Cheshire, R.H.E. Inkson, C.M. Mundie and G.P. Sparling. Submitted to Journal of Soil Science.
9. Digestion and excretion of nitrogen and carbohydrate by the cranefly larvae Tipula paludosa (Diptera, Tipulidae). By B.S. Griffiths and M.V. Cheshire. To appear in *Insect Biochemistry*.
10. A natural direct effect of microorganisms on soil structure development. By R.E. Wheatley and M.V. Cheshire. Abstracts, XIV International Congress of Microbiology, Manchester, 1986, p130.
11. The fractionation of soil polysaccharide by electrofocussing. By M.V. Cheshire and C.M. Mundie to appear in the *Journal of Soil Science*.
12. Characterization of iron-fulvic acid complexes using Mossbauer and EPR spectroscopy. By B.A. Goodman and M.V. Cheshire. To appear in *Science of the Total Environment*.
13. Organo-mineral complexes in relation to pedogenesis. By J.A. McKeague, M.V. Cheshire, F. Andreux and J. Berthelin. Chapter 15 in Interaction of Soil Minerals with Natural Organics and Microbes. Special publication by the Soil Science Society of America. Ed. P.M. Huang, 1986, pp549-592.
14. Mobilisation of micronutrient cations in soil solution in the rooting zone of Barley. By D.L. Linehan, A.H. Sinclair and M.C. Mitchell. To appear in *Journal of Soil Science*.
15. Relative elemental elongation rates along the etiolated hypocotyl of sunflower (*Helianthus annuus* L.) — a comparison of straight and gravitropic growth. By A.R. Berg, I.R. MacDonald, J.W. Hart and D.C. Gordon. To appear in *Botanical Gazette*. 147. 373-382, 1986.
16. A kinetic analysis of phytochrome controlled mesocotyl growth in *Zea Mays* seedlings. By A. Yahalom, B.L. Epel, Z. Glinka, I.R. MacDonald and D.C. Gordon. To appear in *Plant Physiology*.
17. Tropisms as indicators of hormone-mediated growth phenomena. By I.R. MacDonald and J.W. Hart. To appear in *Hormone Action in*

Plant Development — A Critical Appraisal (eds. G.V. Hoad, M.B. Jackson and J.R. Lenton) published by Butterworth Scientific Ltd, Guildford, Surrey.

18. Oxygen induced free radical in wheat roots. By B.A. Goodman, D.B. McPhail and D.J. Linehan. To appear in *Free Radical Research Communications*.

19. 2'-mercapto-4-propylacetanilide : an alternative to thionalide for precipitating lead from weak acid solution. By J.C. Burridge, I.J. Hewitt and H.A. Anderson. *Analyst*, 111, 253-254, 1986.

5. PLANT PHYSIOLOGY

A.E.S. MACKLON

Consideration has been given, during the year, to directing the research programme towards the requirements anticipated for the new Macaulay Institute, incorporating the Hill Farming Research Organisation and MISR. The Department's main concern — studies on uptake, transport and speciation of trace elements, of dietary importance to grazing animals — is envisaged as remaining of central importance for the "hills and uplands" remit of the new Institute, but with the emphasis, for both trace element and nitrogen studies, moving away from arable crops, such as barley and wheat, to upland pasture species.

Characterisation of cobalt uptake in wheat seedlings, has been almost completed this year, and work on copper uptake, transport and speciation in ryegrass is making good progress. These studies on individual trace elements form the basis for interpreting experiments designed to differentiate between interactions which affect the availability of elements for uptake (soil solution effects) and interactions occurring at the uptake step (across root cell membranes). A parallel aim is to understand the mechanisms which limit trace element transport to the shoot, following uptake into the roots. Despite a cut in staff, to take effect next year, we plan to undertake interaction studies as the next phase of the work.

Trace Element Studies

Cobalt Fluxes. With the assistance of analytical data provided by the Department of Spectrochemistry, using graphite furnace atomic absorption spectrophotometry, characterisation of the main features of cobalt uptake and efflux in roots of wheat seedlings has now been completed and an account has been submitted for publication[1]. Linear uptake, necessary for valid compartmental analysis, has been attained by giving the seedlings continuous light after 4 days in complete darkness during germination. It is concluded that uptake from nutrient solution containing 2 μM cobalt is passive into root cell cytoplasm, where the concentration is limited by a metabolically driven active efflux of Co back to the root medium, and active accummulation into root cell vacuoles. The major part of absorbed cobalt is thus stored and removed from the transport pathway to the shoot, at least in the short term.

In last year's report (No. 55, 1985), suspicions of isotope discrimination were entertained, to account for certain features of Co uptake, but further examination of the similarities of uptake between plants grown in the presence of Co, and those given no Co until introduction of ^{58}Co at the start

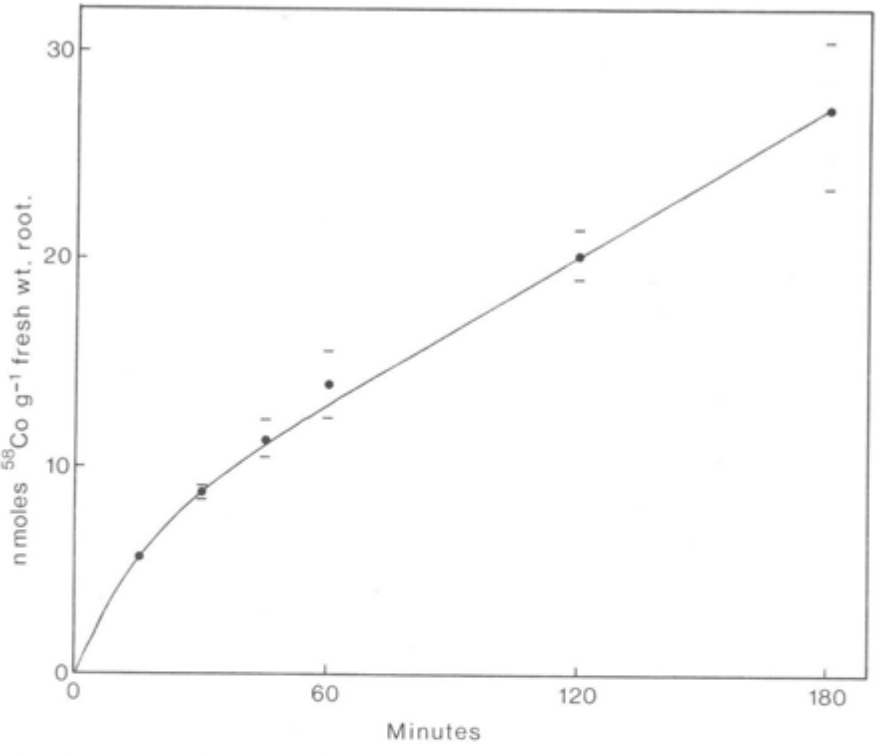


Fig. 5.1. Short term time course of total cobalt uptake by roots of intact wheat seedlings, from a normal nutrient solution containing 2 μM radiolabelled Co as the only micronutrient; pH 5.5. Horizontal bars show s.e.m., where larger than symbol size.

of uptake experiments, have led to the recognition that this is due partly to the large capacity of the roots for Co uptake, which continues in a linear fashion beyond 15 days after germination. At excessively high levels of specific activity, apparent differences in uptake between ^{58}Co and ^{60}Co have been observed, but this has been accounted for largely in terms of the characteristics of the counting equipment at high activity levels.

The possibility of isotope discrimination was partly suspected because of the apparent absence of an exchange "shoulder" in the uptake curve when stable cobalt (^{59}Co) was replaced by radiolabelled cobalt (^{58}Co) in the nutrient solution. However, a more detailed study of the early part of the uptake time course reveals a small "shoulder" (Fig. 5.1). In the absence of major nutrient cations, this shoulder becomes more obvious. Nevertheless, the free space component of root cobalt content is very small compared with uptake into the vacuole (150 nmole g^{-1} fresh wt. root in 17 hours) so that uptake time courses for seedlings given Co before hand and those given no Co pretreatment are similarly almost linear from the start.

Although convenient for experimental purposes, 2 μM Co is at the very top of the range of concentrations likely to be found in solution in

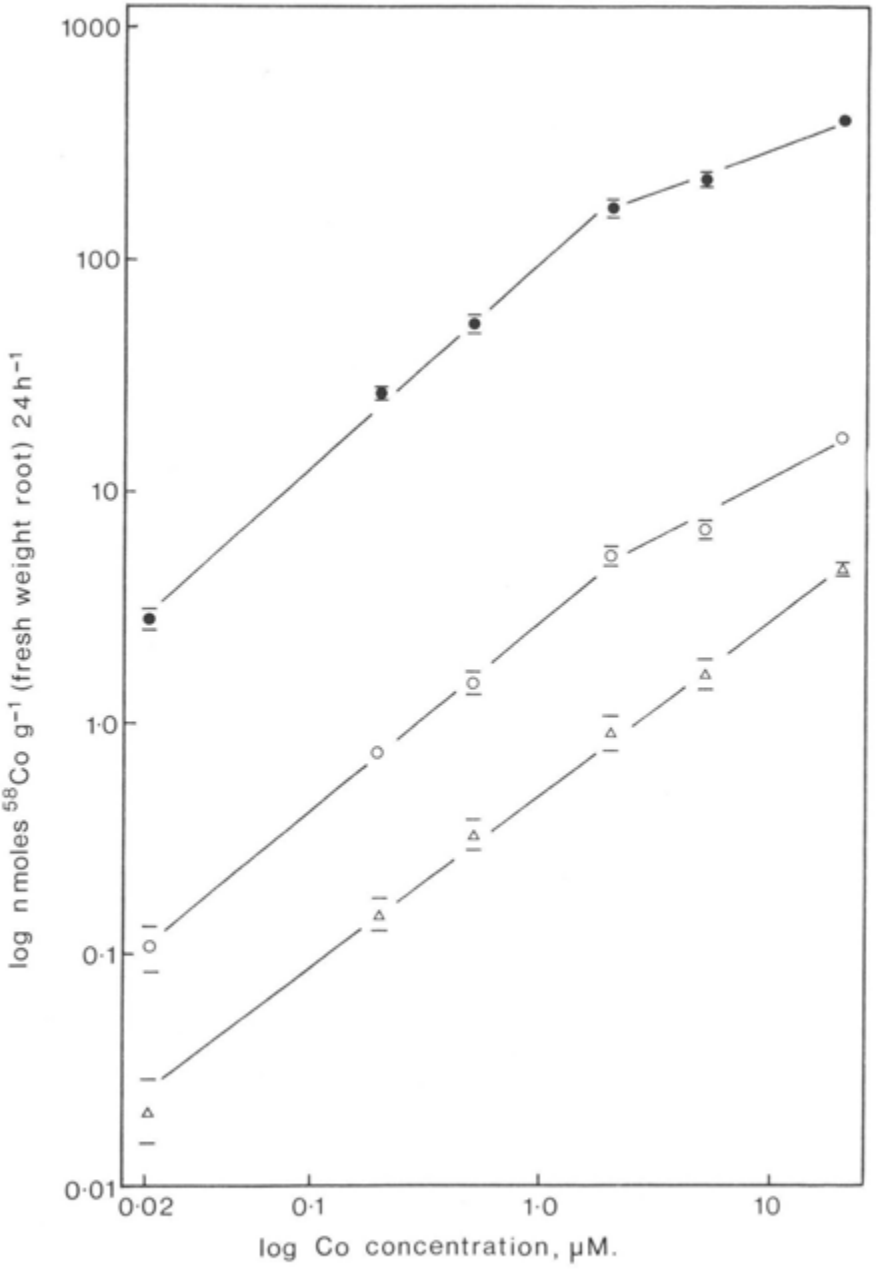


Fig. 5.2. Total uptake (●), transport to the leaves(○) and to the coleoptile (△) of Co over 24 hours from a range of concentrations in nutrient solution containing no other micronutrients; pH 5.5. All values expressed as nmoles ^{58}Co g^{-1} fresh weight of root. Horizontal bars show s.e.m. where larger than symbol size.

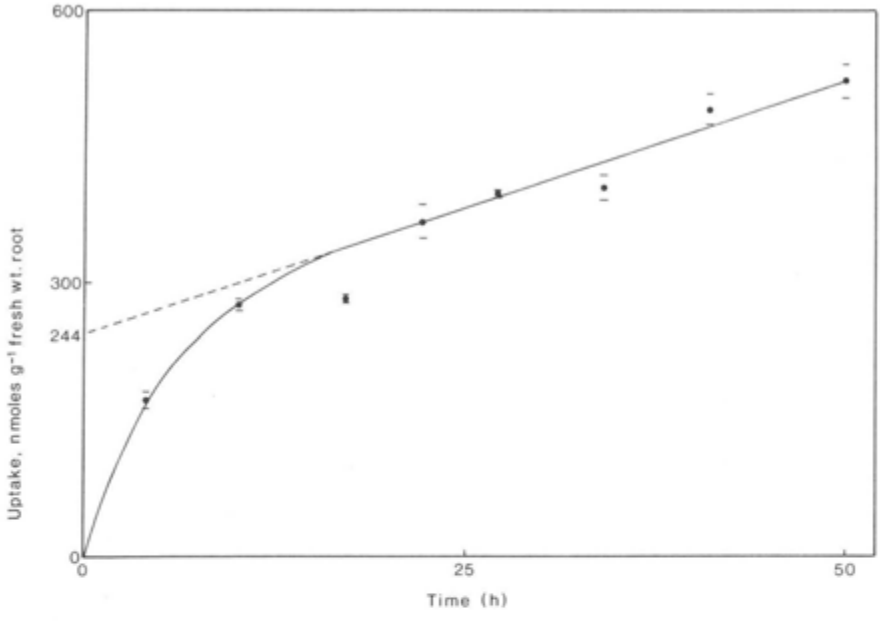


Fig. 5.3. Time course of total copper uptake into ryegrass seedlings. Uptake was from a normal nutrient solution containing 1 μM radiolabelled Cu as the only micronutirent; pH 5.6. Horizontal bars show s.e.m.

agricultural soils. To examine relationships between solution concentrations, root uptake and transport to the shoot, uptake of ^{58}Co was measured over 24 hours over a concentration range from 0.02 to 20 μM Co, in nutrient solution complete for major nutrients. The results (Fig. 5.2) are presented, for convenience, as log/log plots, which show that over the range 0.02 to 2 μM Co there is a linear relationship between log concentration and log uptake, and between log concentration and log transport, and that the two run more or less parallel. This constancy of relationship between uptake and transport is remarkable, when it is remembered how small is the portion of absorbed cobalt which reaches the shoot, and will need to be taken into account when considering the control of cobalt transport. Above 2 μM Co, a change in the relationship between concentration and uptake, and between concentration and transport to the leaves, is evident (although in the coleoptile the original linearity is maintained). The break in the absorption isotherm is considered by those who adhere to the bi- or multiphasic hypotheses of ion uptake, to indicate the operation of a different mechanism of uptake at higher external concentrations of Co, but it may simply be a "saturation" effect. 5050

Some attention has been given to factors which might give pointers to the control of Co transport to the shoot. Commonly, for major nutrient ions, transpirational flux of water through the plant can have an overriding effect on both uptake and transport. However, when controlled environment

equipment was used to expose parallel samples of plants to a range of relative humidities from 40 to 95% R.H., thus giving a range of transpirational fluxes, uptake and transport remained entirely unaffected by the humidity level. Transport of cobalt, would, therefore, seem to be under much more rigid control than that for several major ions. 5050, 5052

Copper Fluxes. Work on the uptake of copper into ryegrass seedlings using ^{64}Cu as a tracer has included a time course of copper uptake as shown in Fig. 5.3. ^{64}Cu uptake shows an initial rapid phase for the first l0 h, then a slower linear uptake of 5.6 nmole g^{-1} (fresh wt. root)h^{-1} over the l0-50 h period. Extrapolating the slower phase back to zero time gives a measure of the total uptake due to the rapid phase alone. The usual interpretation of uptake curves of this nature is that the initial faster phase relates to isotope exchange (^{64}Cu for ^{63} Cu in this case) in the cell wall free space and the cytoplasm, while the later linear phase relates to isotope exchange with and uptake by the vacuole. This time course is more comparable to those obtained for major divalent cations than the cobalt time course presented previously (Annual Report No. 55, l985). Over the l0-50 h time period copper transport to the shoot as measured with ^{64}Cu is 0.05 nmole g^{-1} (fresh wt. root)h^{-1}.

Excised live ryegrass roots show essentially the same time course of copper uptake as the roots of whole seedlings. Killing the roots by briefly dipping them in liquid nitrogen disrupts the cell membranes, destroying the integrity of the cytoplasmic and vacuolar compartments. At present the data for roots killed in such a manner are difficult to interpret due to the fluctuating nature of the data, although in general more copper uptake occurs into dead than live tissue, possibly due to the exposure of fresh copper adsorption sites from within the cytoplasm and vacuole upon killing. Further work being undertaken should allow statistically meaningful differences to the elucidated.

The use of controlled environment cabinets has allowed measurements of copper uptake over a range of relative humidities, all other environmental factors being held constant. Over a 24 h period copper uptake into the shoots and into whole ryegrass seedlings, on a per gram fresh weight root basis, are constant over a range of 44-95% relative humidity although over this range there is a wide variation of water transport. Copper transport to the shoot is about 1.5% of total uptake, over the whole humidity range.

Several amino and imino acid analogues have been tested to help investigate the restriction of copper transport to the shoot. The imino acid analogue of proline, azetidine-2-carboxylic acid (AZ), appears to merit further work in this respect. In ryegrass seedlings grown on a nutrient solution containing copper as the only micro-nutrient, 50 μM AZ caused a reduction in total copper uptake to 25% with respect to an identical solution containing proline at the same concentration. Simultaneously, transport of copper to the shoot was increased to l38% of that for the equivalent solution containing proline. 5050

Copper Speciation. With a view to assaying and isolating the copper

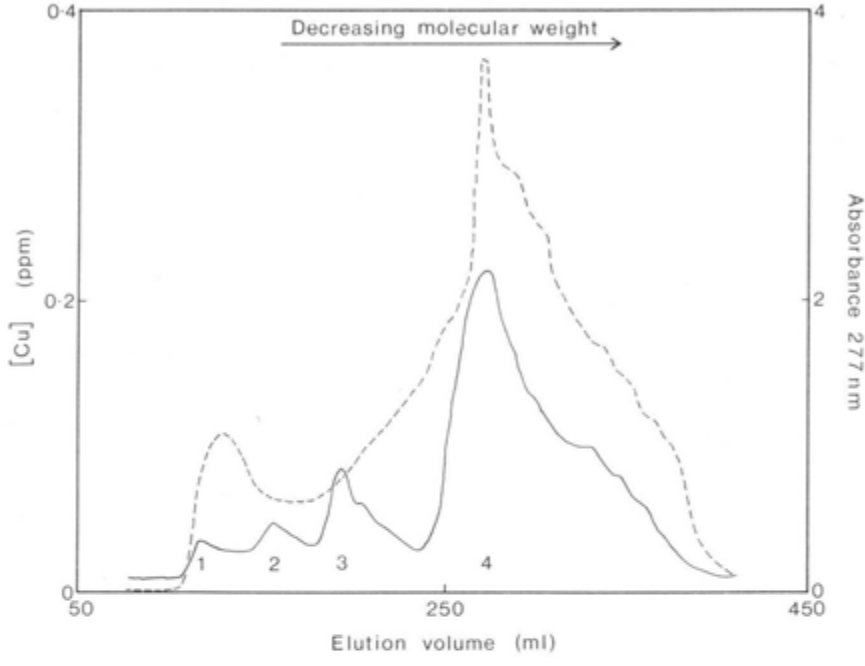


Fig. 5.4. Liquid chromatography gel filtration profile of the 30–80% acetone precipitate extract of ryegrass leaf material showing four distinct copper fractions: 1, high molecular weight; 2 tentative superoxide dismutase; 3, plastocyanin; 4, low milecular weight. ——— [Cu], – – – – – – absorbance at 277 nm.

protein plastocyanin (PC), the molecular weight distribution of copper in different extracts of ryegrass leaf (e.g. Fig. 5.4) has been examined using gel filtration both by liquid chromatography (LC) and, in collaboration with the Department of Spectrochemistry, by high performance liquid chromatography (HPLC).

After an initial homogenisation in 50 mM phosphate buffer, pH 6.8, extracts were prepared from either the supernatant, after centrifugation at 77,000 g, or the fraction precipitating out between 30-80% acetone saturation (redissolved in the same phosphate buffer). The results were similar for both types of extract though the total copper content of the acetone precipitate extract was greater. Both LC and HPLC gel filtration show the majority of the copper present in low molecular weight forms, below the fractionation ranges of the columns used. These copper species were shown to be less than 5,000 molecular weight, using molecular weight cut-off membranes. Both systems also showed a copper-containing species of 12,000-15,000 molecular weight. This was later shown to be PC due to its absorption spectrum peak at 597 nm which only occurs in the oxidised form. In the 30-80% acetone precipitate extract there was a slight indication of a copper-containing species of around 33,000 molecular weight, using

both LC and HPLC. This is tentatively suggested to be superoxide dismutase. Only LC revealed a high molecular weight copper species and this particularly in the "77,000 g supernatant" extract. Preliminary work suggests that when the transformation of grass into hay is simulated by drying under lights, the PC content of the material is reduced.

For solutions containing both the low molecular weight copper species and PC, anion exchange chromatography, using a diethylaminoethyl (DEAE) cellulose column, can be used to separate the two forms of copper present. If the volume of extract applied to such a column is kept low enough to avoid overloading with other anion impurities present in the plant extracts, the low molecular weight copper can be eluted using l0 mM phosphate buffer, pH 7.0. The PC is only eluted when the phosphate buffer strength is raised to 0.2M. Thus, the behaviour of PC on LC and HPLC gel filtration columns has been established together with its behaviour on a DEAE-cellulose ion exchange column. It is planned to develop these techniques to produce an assay procedure for PC applicable to a wide range of starting material, as part of a wider interest in copper availability in ruminants. 5806

Nitrogen Flux Studies

Work with barley seedlings has been terminated in favour of ryegrass, which will have a greater relevance to the remit of the new Institute. Meanwhile, N flux studies on onion root segments have continued, since we have shown that this tissue possesses no nitrate reductase, so that $^{15}NO_3$ absorbed during experiments is not removed from the ion transport milieu by assimilation. This has allowed interpretation of nitrate flux and compartmental studies to be undertaken, and estimates have been obtained of cell compartmental concentrations, undirectional transmembrane fluxes and driving forces on nitrate ions in nutrient solutions containing NO_3 as the sole nitrogen source, and also NO_3 in the presence of NH_4. Experiments are currently being completed to confirm earlier results prior to preparation of a paper presenting the findings.

Similar experiments, designed to examine NH_4 fluxes and compartmentation, are not amenable to exact interpretation due to glutamine synthetase activity in the roots. The presence of assimilatory enzymes for NH_4 had been suspected because it was observed that $^{15}NH_4$ uptake led to tissue contents of ^{15}N much greater than the NH_4 levels measured by chemical analysis. Recently, we have demonstrated that glutamine synthetase is active in roots given N as NH_4, NH_4NO_3 and also as NO_3. We are presently attempting to quantify the levels of enzyme activity in each circumstance.

Although greater progress in exploring NH_4 transport would be possible if an inhibitor specific for glutamine synthetase were available, to prevent $^{15}NH_4$ assimilation from obscuring membrane transport processes involving the NH_4 ion, it may be possible to reach conclusions about the driving forces on NH_4, at least within specified limits. 5051

Ion Fluxes in Tree Leaves

This study is in collaboration with the Department of Forestry, Aberdeen University, and undertaken by a research student working part-time at the Institute. The aim of the project is to examine some of the transmembrane and free space ion transport processes that occur as acid rain passes through the tree canopy. Using the methods that have been developed to study ion fluxes in onion roots, an examination of the ion exchange characteristics of Sitka spruce needles has been carried out. From these studies, a measure of the contribution of ion exchange to throughfall should be possible.

Some work using ^{45}Ca was carried out last year, but interpretation of the results was limited by the large accumulation of calcium in the needles with age. The uptake/efflux experiments have been repeated using young needles which have lower levels of calcium.

The effect of using artificial acid rain for elution was also examined. In analysing the results, the vacuolar content determined by the previous experiments was used, as the total calcium present is not all available for exchange.

Similar experiments have also been carried out using ^{36}Cl and ^{42}K. It was necessary to establish a method of extracting chloride before the radioisotope experiments could be carried out. Two hot water extractions of ground-up needles seemed to extract most of the chloride. Unextracted Cl was counted using a planchet counter, and accounted for less than 2% of the total.

Previously, isotope uptake had been carried out in the dark and the efflux under normal room lighting. A comparison of uptakes in the dark and under a battery of lights was carried out. No significant difference between the two was noted. 5050

Growth and Morphology of Sphagnum

This pilot study aims to explore methods of growing *Sphagnum* species rapidly and in large amounts, free from plant and microbial contaminants, and to define optimum growing conditions for selected species. This has been funded for a two year period by the HIDB and extended for a further eleven weeks to the end of 1986 by joint financial support from Courtaulds plc, the Institute of Orthopaedics (Stanmore), and Vernon-Carus Ltd.

Experiments with an enclosed hydroponic-type system, using axenically cultured initial inocula of several *Sphagnum* spp., have taken place over an eight month period. These all grew successfully although algal contamination of the *Sphagnum* remained a problem. This could, however, be significantly reduced by introducing a filter into the nutrient solution line at a point prior to the spraying of the plants.

Emphasis has been placed on the development of submerged axenic culture methods and this has produced encouraging results. Most significantly, investigations exploring the influence of nitrogen, potassium, phosphorus and carbon supply on growth and morphology of *Sphagnum* have been undertaken. An account of the findings are contained in a report to the HIDB[2].

A scanning electron microscope study of the distribution of pits, thought to have a transport function, in several *Sphagnum* species, has been submitted for publication[3]. 5072

Other Investigations

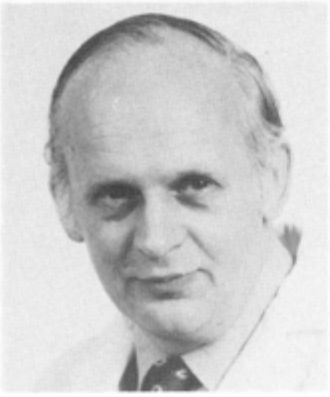
In collaboration with the Department of Soil Organic Chemistry, experiments defining the optimum growing conditions of axenically cultured *Lemma gibba* L. have been undertaken as part of a ^{14}C-glucose radiolabelling study. This has concentrated on the use of natural and synthetic chelating agents to mediate nutrient availability. 4064

References

1. Cellular cobalt fluxes in roots and transport to the shoots of wheat seedlings. By A.E.S. Macklon and A. Sim. Submitted to Journal of Experimental Botany.
2. A study of factors affecting the growth and morphology of *Sphagnum*. By R.G.E. Baker and A.E.S. Macklon. Final report to HIDB, 1986.
3. The morphology and distribution of pits in the cell walls of *Sphagnum*. By R.G.E. Baker. Submitted to New Phytologist.

6. MICROBIOLOGY

J.F. DARBYSHIRE



Most of the research in the Department of Microbiology is concerned with microbial transformations of soil organic matter and the subsequent assimilation of some of these microbial nutrients by plant roots. Many of the studies are concerned with the rhizosphere, the complex interactions between the microflora and microfauna in soils and with mycorrhizae. Interdisciplinary collaboration exists amongst members of the Department and with other scientists elsewhere in the Institute and outside.

Interrelationships Between Plant Roots and Microbes

Recent improvements in the soil thin section technique, described in the previous Annual Report, have been published[1]. Root morphology and decomposition of perennial ryegrass, spring barley and peas were observed with this technique using plants growing in a heated glasshouse for up to one year, i.e. for many weeks after the barley and peas were senescent. Similar observations were made on roots in the surface soil of a semi-permanent grassland at the University of Aberdeen farm. In perennial ryegrass and barley, the first signs of cell wall decomposition in roots occurred in the inner cortex and this led to the development of large voids in this region. In some instances with perennial ryegrass, the central vascular tissue became completely surrounded by a large cortical void. In barley, the cortical voids did not encircle the vascular tissue, although they often became well developed. In contrast, the cortical cell walls of peas decomposed from the outside of the root and the cortex was sloughed off after the onset of secondary thickening. In all three species, the vascular cylinder was the last identifiable root residue. Fungal hyphae were sometimes observed in the cortical voids and in the residual vascular cylinders. The decomposition of roots in the grassland followed a similar pattern to that observed in perennial ryegrass growing in the glasshouse. Most of the roots observed in the soil thin sections were distorted to some degree. These observations are being prepared for publication and were presented at the 5th International Symposium on Microbial Ecology.

6025, 6027, 6028, 6031

Studies of the microbial activity in soil beneath Sitka spruce planted in pure stands or mixed with Scots pine have been concluded. The results of these studies were discussed in the previous Annual Report and are being prepared for publication. The glasshouse experiments concerned with the

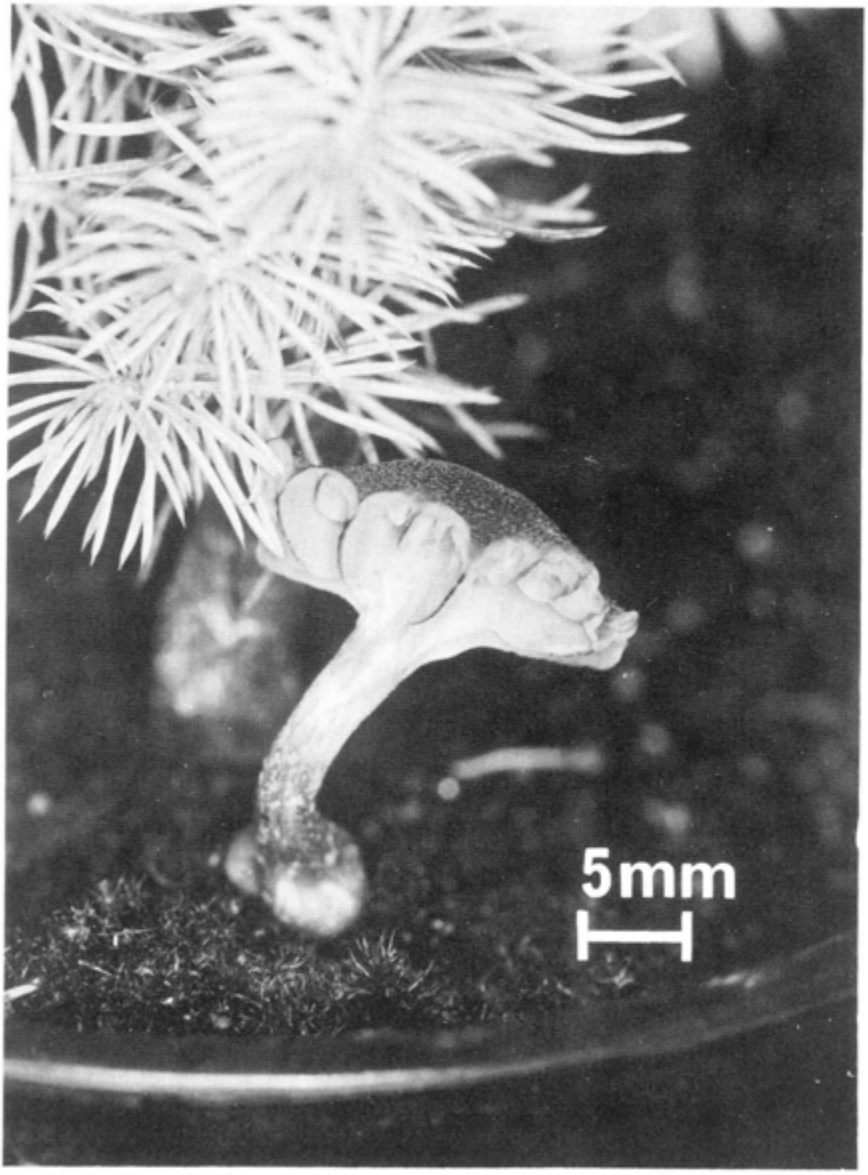


Fig. 6.1 Seedling of Sitka spruce (*Picea sitchensis*) with fruiting body of ectomycorrhizal fungus(*Laccaria laccata*).

role of mycorrhizas in the mixed stands are being continued for another year. The mixture of seedlings of Sitka spruce, Scots pine and Lodgepole pine in these glasshouse experiments have been inoculated with either the mycorrhizal fungus, *Laccaria laccata*, (Figs. 6.1, 6.2) or mycorrhizal

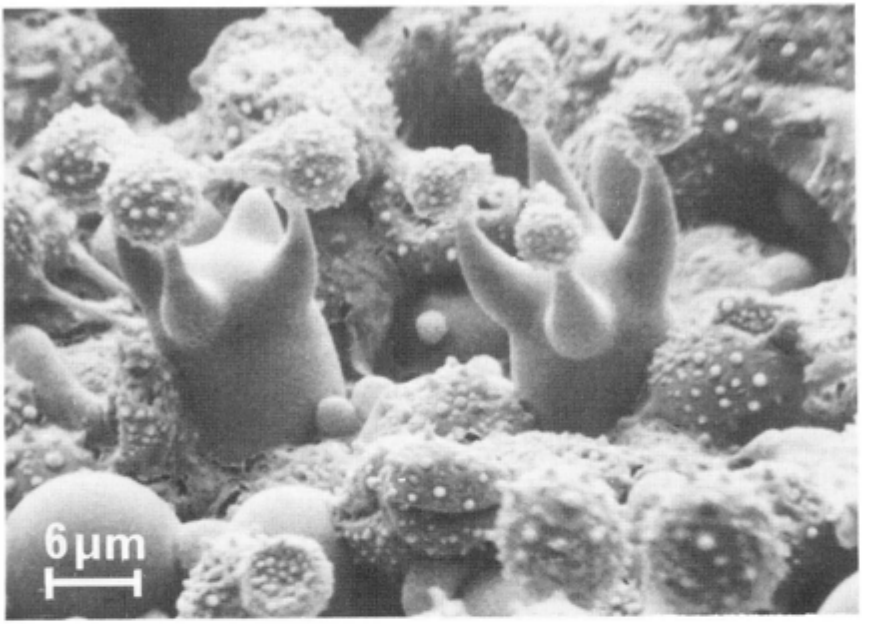


Fig. 6.2 Scanning electron micrograph of gill surface on fruiting body of *Laccaria laccata* shown in Fig. 6.1. Cryofixed specimen.

inocola from mixed stands of Sitka spruce and Scots pine at the Culloden experiments. 2055, 2807/6807, 6027

Microbial composting of tree bark continued to be studied with the aim of eliminating the phytotoxins present in fresh bark and conserving the phytosanitary compounds. As earlier results have been reported in the last two Annual Reports, at the 14th International Congress of Microbiology[2] and the November meeting of the Society for General Microbiology concerned with the biodegradation of ligno-cellulosic materials, only a summary of the results will be presented in this Report. The optimal moisture content of the coniferous bark for rapid decomposition was confirmed to be 60%. A comparison between the microorganisms present on bark composted at 40°C and 50°C showed that *Aspergillus* spp. grew and produced spores more prolifically at the lower temperature. As *Aspergillus* spp., particularly *A. fumigatus*, can cause serious allergic reactions and respiratory disease in humans and there was no significant difference in the decomposition rates at these different temperatures, 50-60°C is the optimal range of temperature for composting bark. Above 60°C, there is a tendency for some beneficial microorganisms to be suppressed. At 50°C, the commonest fungi on the bark belong to the genera *Talaromyces*, *Rhizomucor* and *Thermoascus* (Fig. 6.3). There is often a bacterial film covering the bark particles at 50°C and yeasts have also been found at this temperature. The most rapid loss of phytotoxicity occurred at temperatures above 50°C and was closely correlated with the volatilisation

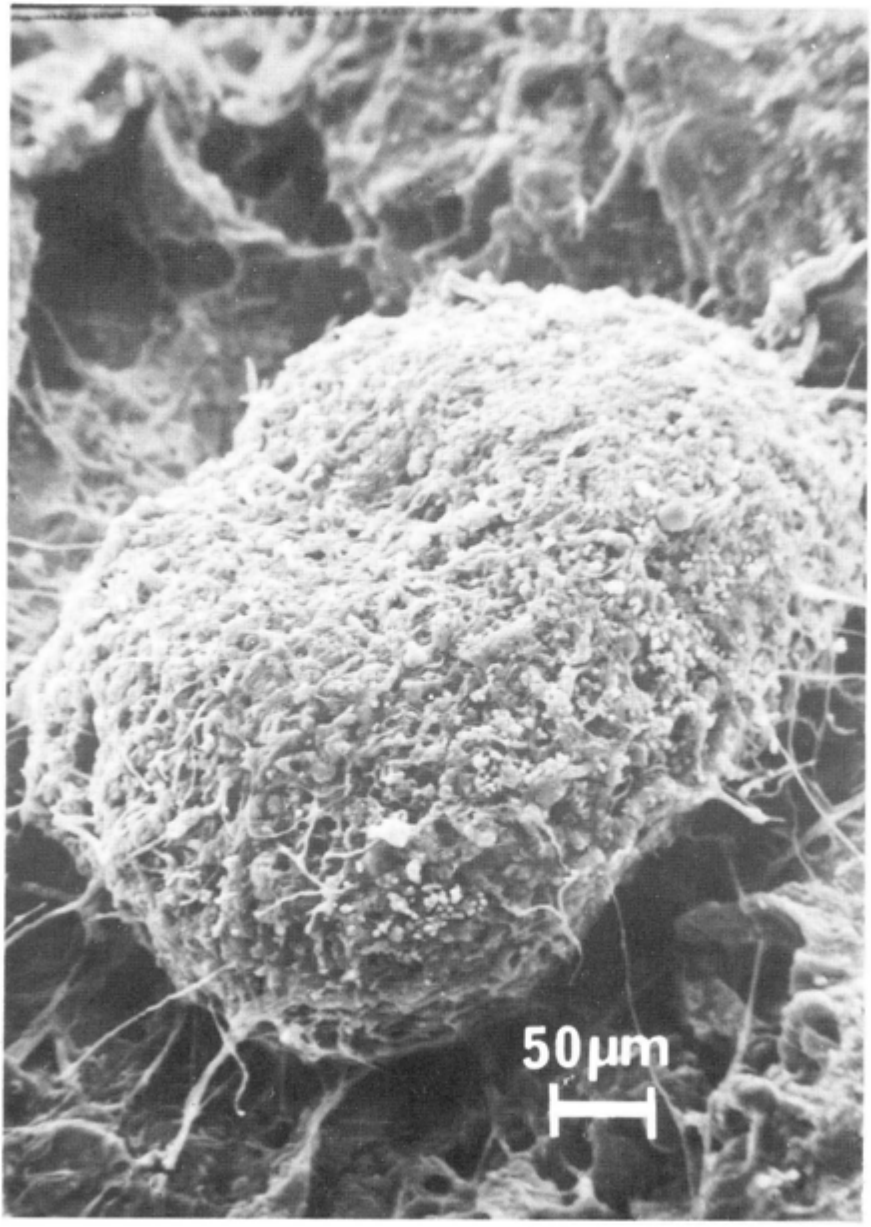


Fig. 6.3 Cleistothecium of *Thermoascus* sp. growing in composted bark at 50°C.

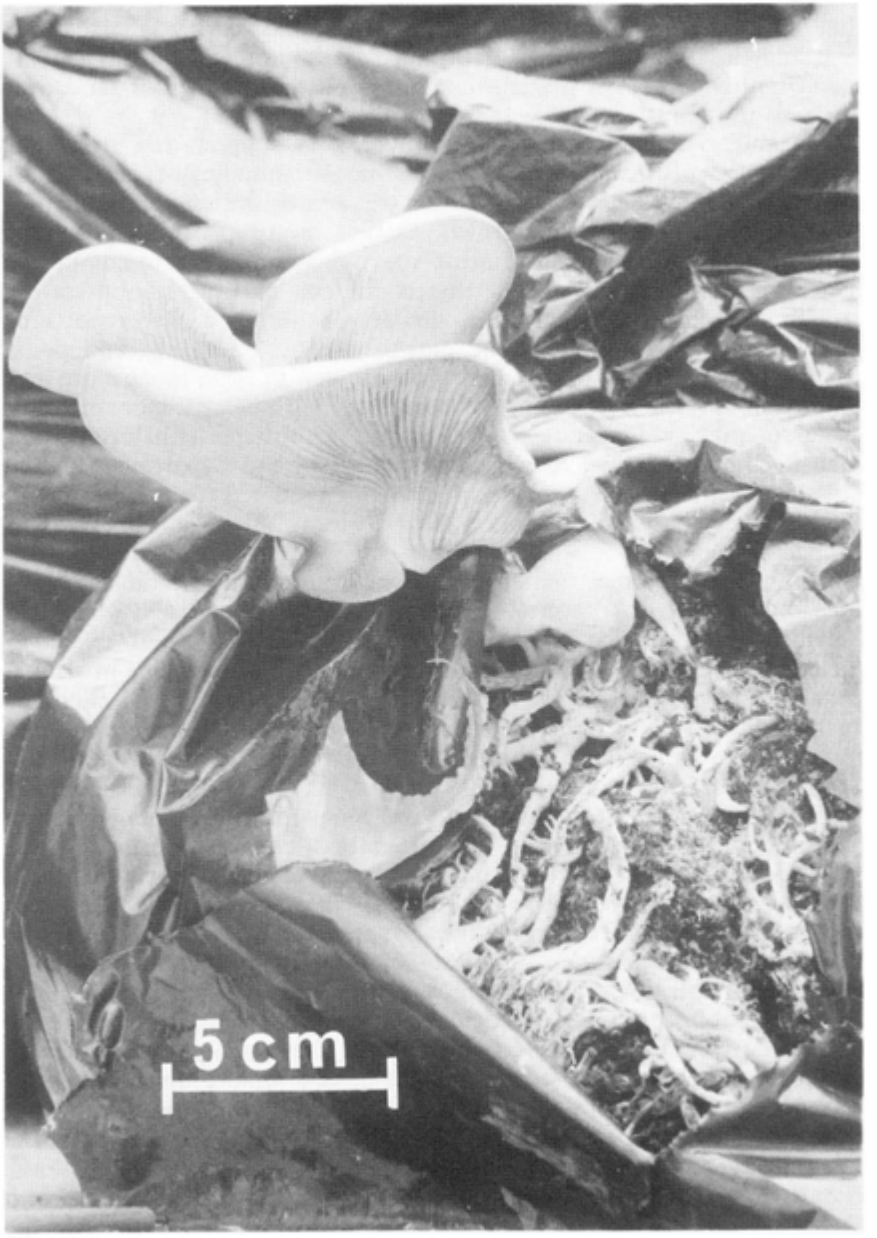


Fig. 6.4 Edible fungus, *Pleuotus cornucopiae* growing on composted bark of Norway spruce, *Picea abies*, in a black plastic bag.

of resins and monoterpenes from the bark. The suitability of the composted bark for use as a plant medium was tested with tomato plants. It was found that plant growth was improved when the composted bark was mixed with peat and the optimal ratio of bark and peat for tomatoes was 1:3. This mixture provided better growth than either peat on its own or sand/peat mixtures in the ratio of 1:3.

The ability of composted coniferous bark to suppress the growth of *Rhizoctonia solani*, a common cause of the damping-off disease of seedlings, was investigated using *Celosia* seedlings as the test plants and peat as a control medium for plant growth. Only the peat supported saprophytic growth of *R. solani* and the fungus was not recovered from composted bark. The observations suggest that coniferous bark may suppress the growth of some pathogens in a similar manner to earlier reports of hardwood barks suppressing the growth of root pathogens and pests. Composted coniferous bark can also absorb two to three times more iron than fresh bark. The possibility of composted bark being a more effective agent for preventing the deposition of iron ochre deposits in field drains than uncomposted bark is being investigated by the Department of Soil Organic Chemistry and a joint paper is being prepared for publication on this discovery. Composted bark can also absorb significant amounts of copper, manganese and silage effluents.

During these composting studies, it was found that an edible fungus, *Pleurotus cornucopiae* (Fig. 6.4), can grow profusely on bark, which had previously been composted for two weeks[3]. This fungus is closely related to the edible so-called Oyster mushroom and efforts are now being made in a collaborative project with the Department of Bioscience and Biotechnology at the University of Strathclyde to increase the yield of *P.cornucopiae* and to extend the range of edible fungi, which can be grown on this abundant Scottish natural resource. 6025, 6026, 6027

Further use has been made of low temperature scanning electron microscopy (SEM) to study the ultrastructure of ectomycorrhizas of trees. A paper dealing with this topic has been submitted for publication[4] and a lecture and a joint poster with the Department of Mineral Soils were presented at the 14th International Congress of Microbiology[5]. At the Royal Microscopical Society 'Micro-86' meeting in London, a similar lecture was presented[6]. These posters and lectures emphasized the advantages of cryofixing biological specimens rather than relying on chemical fixation and critical point drying. One major disadvantage of cryofixation is that the specimens cannot be re-examined on a subsequent occasion. Cryosections of ectomycorrhizal roots of Beech (*Fagus sylvaticus*) were cut when a LKB Cryo-Nova cryoultratome was demonstrated at the Institute. These sections were examined in a Jeol JL 100 SEM at the N.E.R.C. Marine Biochemistry Unit in Aberdeen. Previous workers with these mycorrhiza reported the presence of electron-dense granules in the fungal mantle surrounding the root cortex. These granules were said to be rich in phosphorus and calcium, but had low concentrations of potassium, chlorine and sulphur. Similar granules were found in the fungal mantle surrounding the beech root in the recent investigation, but when the

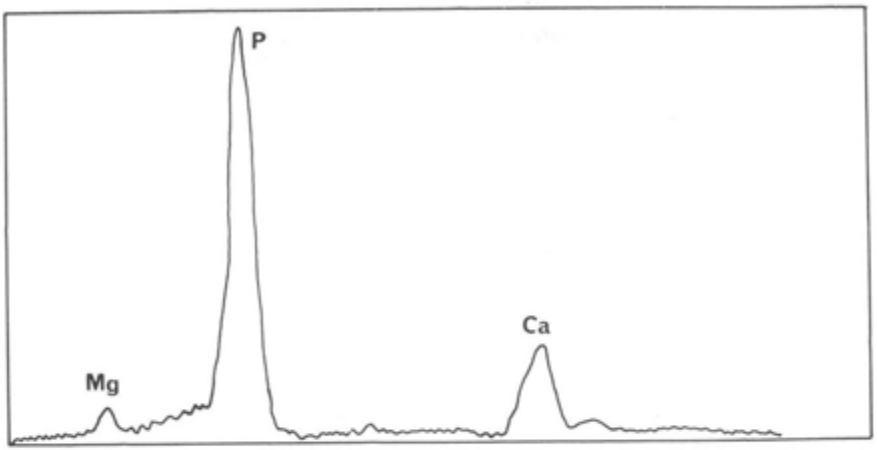


Fig. 6.5 Energy dispersive X-ray spectrum of cryosection of ectomycorrhizal roots of Beech (*Fagus sylvaticus*).

contents were analysed by X-ray microanalysis they were found to be rich in magnesium as well as calcium and phosphorus (Fig. 6.5). It is suggested that in these earlier investigations, the magnesium was removed from the granules during the fixation and embedding procedure. It is well established that the fungal partner in the mycorrhizal association increases the uptake of phosphorus by the host plant and probably the phosphate-rich storage granules found in the fungal sheath represents temporary accumulations of vital plant nutrients. What happens to the calcium and magnesium in these granules after the phosphorus is transferred to the host plant remains to be determined by future research. 6026

Organic Matter

Microbial Synthesis. Further studies on the antibiotic, vermiculine, from the soil fungus, *Talaromyces wortmannii*, have characterized the nature of the crystals of this antibiotic using X-ray diffraction and scanning electron microscopy in collaboration with the Department of Mineral Soils [7,8]. This antibiotic is a powerful agent against many bacteria and protozoa. A new fungal secondary metabolite, 5-hydroxymaltol, was detected in culture filtrates from *Penicillium echinulatum* and these results were presented at the 14th International Microbiology Congress[9]. Another metabolite from *P.echinulatum* was mycophenolic acid, which is known to be detrimental to bacteria and other fungi. Mycophenolic acid has been isolated from other species of *Penicillium*, but not from *P.echinulatum*. Another crystalline material from *P.echinulatum* is being characterised using a variety of techniques including nuclear magnetic resonance, mass spectrometry and infrared spectrometry. This study is being pursued in the hope of explaining why *P.echinulatum* is so antagonistic to several other soil fungi, including species that invade plant roots.

Polysaccharides In collaboration with the Department of Soil Organic Chemistry, the effects of four bacteria (*Azotobacter chroococcum*, *Bacillus subtilus, Beijerinckia indica*, *Leuconostoc mesenteriodes*) and one fungus (*Penicillium thomii*) on soil aggregation have continued to be studied. The exopolysaccharides from the bacteria have uronic acid contents ranging from zero to 70%. Preliminary results suggest that the fungus was more effective in improving aggregate stability than any of the bacterial species and irrespective of the uronic acid content of the polysaccharide. These microorganisms in pure culture appear to have little effect on the aggregate stability of soil samples from the C horizons. Further trials are in progress with soil samples amended with either glucose or sucrose at regular intervals. 4020, 6027

Biomass. The soil microbial biomass represents an important reservoir of nutrients. Some of the nutrients may become available to plant roots and consequently any further information about the quantities of nitrogen present in the biomass should improve future predictions of nitrogen fertiliser requirements by crops in different environmental conditions.

The size of the microbial biomass present in the soil at different depths below a potato crop has been estimated using the fumigaton technique at intervals throughout 1986 in collaboration with the Department of Soil Fertility[11]. The levels of nitrogen present in the biomass were also estimated by fumigation. Part of the crop was fertilized with nitrogen at 200 kg ha^{-1}. As this fertilizer was labelled with ^{15}N, the amounts of the fertilizer assimilated by the microorganisms could be calculated. Comprehensive analysis of these results have not been completed, but preliminary results indicate that the biomass carbon and nitrogen in the topsoil was usually 5 to 10 times greater than in the subsoil. The addition of fertilizer does not appear to influence the size of the microbial biomass. Similar investigations on spring barley at the experimental plots at Cross of Jackston await the completion of statistical analyses. 6027, 7039

A modification to the Jenkinson fumigation method of estimating carbon has been accepted for publication[12]. This modification involves the use of a 10% inoculum in the fumigated soils and a control for 0 to 10 days. This modification appears to be particularly appropriate for acid soils with a pH of less than 4.5. Another paper, which is in the press compared the efficiency of different extractants for biomass sulphur for a series of local soils[13,14]. It was concluded that $CaCl_2$ was the best extractant. The proportion of biomass sulphur actually released by chloroform fumigation is being estimated in current experiments using ^{35}S-labelled microorganisms. The preliminary results indicate that fumigation and $CaCl_2$ extraction were largely complete after 24 and 1 h respectively. There was evidence that some ^{35}S from the microorganisms added to the soil was adsorbed to the soil particles after fumigation and that this proportion varied with the soil type. 6027

The immobilization of a significant proportion of the soil sulphur in the microbial biomass after the addition of carbohydrates has been studied further. The microbial biomass in other local soils besides those listed in the

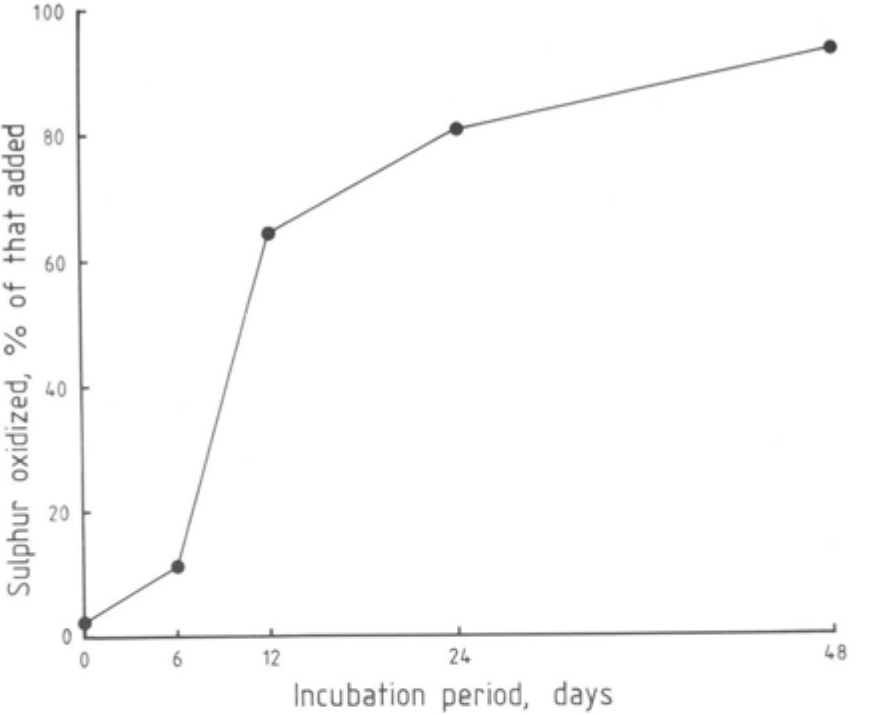


Fig. 6.6 Oxidation rate of micronized sulphur ('Thiovit') in a soil of the Boyndie association at 14°C.

previous Annual Report has been shown to be sulphur-deficient. Cellulose was the best substrate; glucose was only effective in soils with a very low level of sulphur. Amendments with barley straw only caused slight sulphur-deficiency, probably because the straw itself contained sulphur. This respirometric method of studying sulphur deficiency in the microbial biomass in the presence and absence of added sulphate is being tested as a possible means of estimating the sulphur status of different soils. A paper dealing with the mineralization of sulphur in soil from ^{35}S labelled ryegrass shoots is in preparation.

Further estimates of the numbers of sulphur-oxidizing microorganisms in local soils have been made. In the six soils examined, heterotrophic sulphur oxidisers were present with most probable counts of $1.8 \times 15^5\ g^{-1}$, but only half of the soils contained any autotrophic thiobacilli (*Thiobacillus thioparus* type) with counts between $5.5\ g^{-1}$ and $2.4 \times 10^4\ g^{-1}$ soil. No autotrophs of the *T.thiooxidans* type were detected, although this type was abundant in a mud sample collected from a pond within the grounds of the Institute.

A preliminary investigation has been made of the rate of oxidation of elemental sulphur in local soils. The oxidation rate of a micronized form of elemental sulphur, 'Thiovit', was rapid in a soil belonging to the Boyndie

Association when incubated at 14°C (Fig. 6.6). After 24 days, 80% of the Thiovit was oxidised compared with only 20% oxidation for flowers of sulphur. As expected, decreasing the incubation temperature reduced the rate of oxidation, but even at 7°C more than 50% was oxidised in the first 24 days. Some differences between soil types was noted, for example, there was a faster rate of oxidation in some Countesswells and Boyndie soil than soil from the Laurencekirk association. 6027, 7038

Studies have continued on the effects of chloroform fumigation and air-drying on the levels of trace elements in soils with heavy texture. Only manganese gave a flush following fumigation in all soils. The availability of other elements even appeared to decrease after fumigation or air drying. 3007, 6027.

The development of suitable methods for extracting microbial cells from soil has continued. The extraction procedure entails a gentle dispersion of the soil to release the soil microbes, followed by the separation of the cells from the mineral particles on a Percoll density gradient. A range of anionic, cationic and neutral surfactants as well as Tris buffer and water were tested for their effectiveness to release microorganisms from soil and their toxicity to microorganisms. Compared with water the surfactants tended to reduce the total volume of cells extracted. Tris buffer increased the total volume of cells extracted compared with water. Increasing the dispersion of the soil by physical treatments increased the number of cells extracted, but the total volume of cells extracted was greatest when the soil was shaken with Tris buffer. The number and dimensions of the separated cells were observed with UV epiillumination. The use of fluorescent stains specific for DNA and protein made it possible to identify eukaryotic cells (Plate 6.7). Dehydrogenase activity in microbial cells can be identified by the production of coloured formazan from iodonitrotetrazolium salts. The formazan is deposited as discrete granules in the cells and can be easily detected with bright-field optics. 6027

Soil Invertebrates. The decomposition of plant and animal remains can be enhanced by soil invertebrates in several ways, by their own digestive enzymes and enzymes released by microorganisms resident in their own alimentary canals, by comminution of their food and by stimulating microbial activity in the surrounding soil. Comparative studies on several animal groups have been made in an attempt to understand in detail how soil animals influence plant decomposition and the release of nutrients to the soil and plant roots.

The new method of cultivating enchytraeid worms, reported in Annual Report No. 54, was used to investigate what effect these worms have on nutrient cycling in Sitka spruce litter. Any enchytraeids resident in the litter were killed by freezing the litter before the start of an experiment. The litter was placed in a series of glass columns and half of the columns were inoculated with enchytraeids (200 per column). The populations of enchytraeids multiplied and reached about 1400 per column after 16 weeks, but no significant difference in the microbial biomass as determined by the Anderson and Domsch method, could be detected between the columns

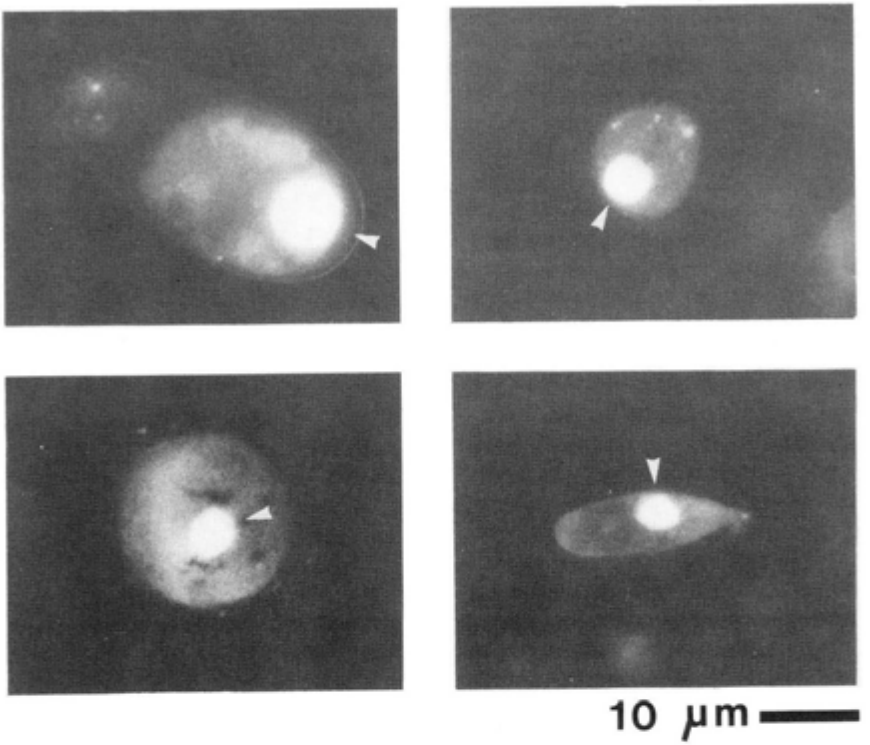


Fig. 6.7 Epifluorescence micrographs of microbial cells extracted from soil and stained with acridine orange and DAPI (4,6-diamidino-2-phenylindole). Arrows indicate nuclei.

with and without enchytraeids. Chemical analyses of the litter suggest that enchytraeids had no effect on the levels of nitrogen and phosphorus in the litter, but differences between the treatments may be detected when the leachates are analysed for Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+, NO_3^- and PO^{3-}_4.
2807, 6027

A paper describing the effects of two groups of bacterial predators, a mixed sample of protozoa and nematodes from a field soil sample, on the mineralization and uptake of nitrogen by ryegrass plants has been submitted for publication[15]. The mineralised nitrogen was only assimilated by ryegrass roots, if the roots were well developed throughout the mass of soil at the time when the protozoa were most active.

Ethylene oxide fumigation was found to inhibit the growth of any microorganisms or seedlings subsequently introduced into the sterilised soil sample. Consequently, the series of experiments concerned with the effects of bacteriophagous ciliates and nematodes on the flux of nitrogen and phosphorus from bacteria after ethylene oxide fumigation (Annual Report No. 54, p. 114) were repeated using soil sterilized by γ -irradiation. It was found with both forms of sterilization that the nematode, *Rhabditis* sp,

stimulated bacterial populations, which led to increased numbers of the ciliate, *Colpoda steinii*, and to a corresponding increase in the mineralization of NH_4^+-N. These bacterial predators had no effect on the mineralization of phosphorus. The results of this study have been accepted for publication[16]. A report, recommending the sterilization of soil by γ-irradiation rather than ethylene oxide before use in microbial studies has also been accepted for publication[17]. Another study of the bacteriovores, the ciliate, *Colpoda steinii*, and the nematode, *Rhabditis* sp., on the uptake of nitrogen and phosphorus by ryegrass (Annual Report No. 55, p.127) has been accepted for publication[18]. In soil at 30% water-holding capacity, the presence of both ciliates and nematodes increased the nitrogen content of the ryegrass. When the soil was allowed to dry out and rewetted at regular intervals, only the ciliates responded rapidly enough to mineralize significant amounts of nitrogen to benefit the ryegrass plants. Nematodes with longer generation times than protozoa were unable to respond quickly enough to benefit from such conditions. 6027

The results of chemical analyses of the food and faeces of the common leatherjacket, *Tipula paludosa*, referred to in the last Annual Report have been accepted for publication[19]. Similar chemical analyses, involving infra-red spectrometry, pyrolysis-mass spectrometry and radioisotopes have been completed on an extended range of British detrivorous arthropods from soil. The food and faeces of three common detrivorous termites, *Zootermopsis nevadensis*, *Cubitermes ugandensis* and *Macrotermes michaelsoni* from tropical Africa were studied for comparative purposes. The main foods of *Z.nevadensis*, *C.ugandensis* and *M.michaelsoni* are wood, soil and fungi respectively. It was found that these termites digested far more of their food than the temperate woodlice (*Oniscus asellus*, *Porcellio scaber*, *Armadillidium* vulgare) or millepedes (*Glomus marginata*, *Cylindroiulus punctatus*). The protein and carbohydrate fractions in the food of these termites were severely depleted during passage through the alimentary canals, but the same components were largely unchanged after passage through these temperate woodlice and millepedes. These studies, using new methods of chemical analysis, re-emphasise the importance of termites as agents of decomposition in the tropics and also show that the effects of temperate detrivorous woodlice and millepedes on plant decomposition are very different from the temperate herbivorous leatherjacket, *T.paludosa*, which can digest most of the cellulose and protein in its food. Although the symbiotic protozoa and bacteria in the termite gut are well known to play important roles in termite digestion, the possibility of promoting decomposition in temperate regions by inoculating the same symbiotic microorganisms from termites into temperate detrivorous arthropods is only an intriguing possibility at present, that may follow from increased attention being paid to invertebrate/microbial interactions in the soil. These present studies, which are in collaboration with the Departments of Mineral Soils, Spectrochemistry and Soil Organic Chemistry at the Institute and the Department of Biological Sciences, Queen Mary College, London, are being prepared for publication. The effect of the woodlouse, *P.scaber*, on the decomposition of plant material

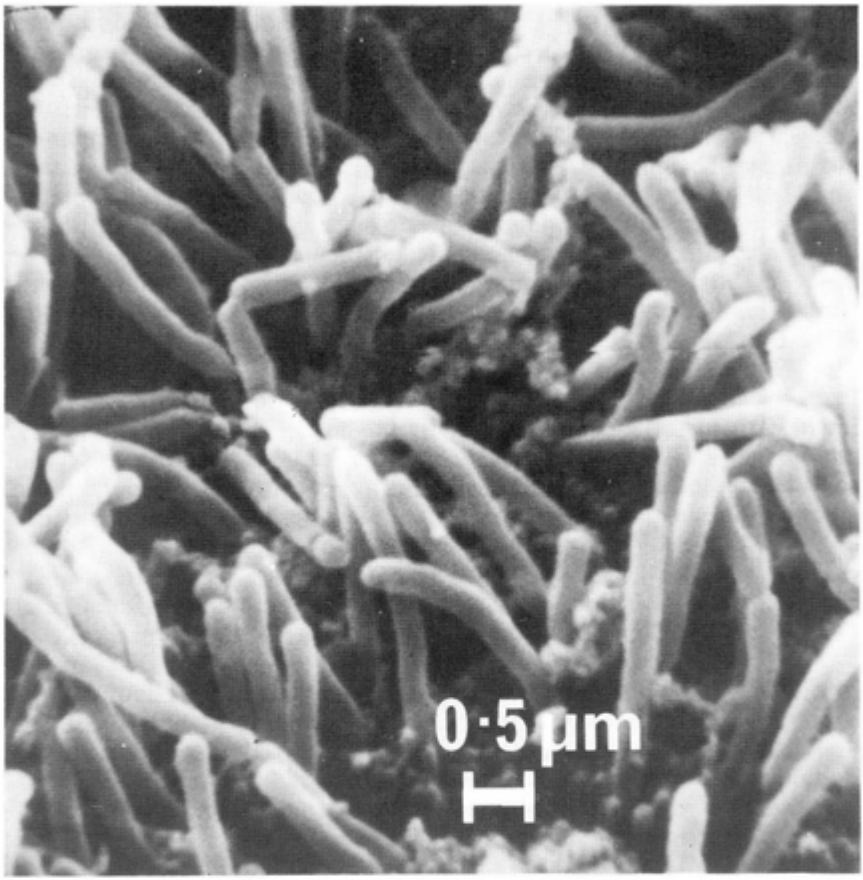


Fig. 6.8 Scanning electron micrograph of bacteria lining the wall of the hepatopancreas of the woodlouse, *Oniscus asellus*.

has also been studied with ^{14}C-labelled leaves of the duckweed, *Lemna gibba*. The chemical analyses have not been completed, but it is known that more $^{14}CO_2$ is evolved in the presence of these woodlice than in their absence. 1018, 3017, 4020, 6027

The results of a study of the microorganisms colonizing the hindgut of the woodlouse (*O.asullus*), discussed in the previous Annual report, have been published[20]. The results of studies of the bacteria colonizing the hepato pancreas of *O.asellus* and *P.scaber* have been presented as a poster at the 14th International Congress of Microbiology[21] and are being prepared for publication. Apparently pure cultures of bacteria are present in these organs (Fig. 6.8). Isolates from the hepatopancreas of these two species of woodlice appear to be different species, although it has not been possible to grow these bacteria on any one of a wide range of media. A small survey of woodlice from different sites in Britain has shown that the incidence of

Table 6.1. Percentage of individual woodlice with bacteria in the hepato pancreas.

Species	Site	Date	% with bacteria
O.asellus	Moore's Wood, London	April 1986	28
O.asellus	Mill Hill, London	April 1986	8
O.asellus	Macaulay Institute	April 1986	9
O.asellus	Macaulay Institute	September 1985	47
P.scaber	Macaulay Institute	September 1985	34

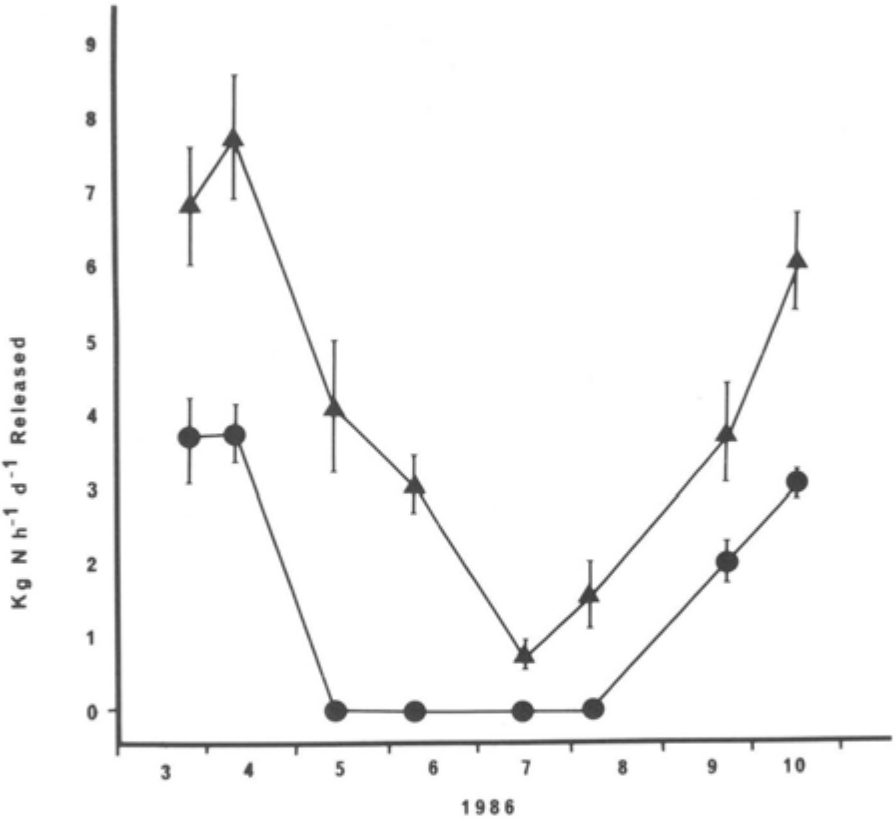


Fig. 6.9 Potential rates of denitrification in a a deep peat from Sletill Hill, Caithness.

bacteria in the hepatopancreas varies between seasons, sites and different species of woodlouse (Table 6.1). 6027

The results of the chemical investigations of the exoskeleton of *O. asellus*, described in the last Annual Report, are now in the press[22]. These results have also been presented as a poster at the 14th International Microbiology Congress[23]. During decomposition of the exoskeleton, there was an increase in the microbial biomass and the concentration of ammonium-N. The microbial decomposition of the exoskeleton was restricted by the presence of calcium carbonate, which protected some of the chitin from microbial attack. 6027

Peat microbiology. The fate of nitrogen fertilizer applied to grass leys on deep peat in Caithness has continued to be studied in collaboration with the Department of Peat and Forest Soils. Spring applications of NH_4NO_3 produced little increase in growth. An assessment of the rate of denitrification throughout the year was made using the acetylene block technique on peat cores removed from the site at intervals. These investigations showed that there was a marked seasonal pattern in the potential rates of denitrification (Fig. 6.9) with very rapid rates in the spring and early summer, a decline in the late summer followed by a second increase in autumn[24]. The possible factors controlling these changes in denitrification are being investigated. Ammonification and nitrogen immobilisation are very rapid during the year, but nitrification was not detected. 2055, 6027

Microbiological Weathering. Two lectures dealing with microbiological weathering of minerals in collaboration with the Department of Mineral Soils were given at the University College of North Wales and at the University of Texas. A review of biomineralization in crustose lichens has been published[25]. Another review on lichens and pedogenesis is in the press[26].

References

1. The preparation of soil thin sections for biological studies. By R. Tippkötter, K. Ritz and J.F. Darbyshire. *Journal of Soil Science 37*, 681-690, 1986.
2. Microbial decomposition of coniferous tree bark. By C.D. Campbell, J.F. Darbyshire and J.G. Anderson. Abstract P.B313-23, 14th International Congress of Microbiology, Manchester, 84, 1986.
3. Growth and fruiting body formation of *Pleurotus cornucopiae* on composted conifer bark. By C.D. Campbell, J.F. Darbyshire and J.G. Anderson. Abstract P.B13-24, 14th International Congress of Microbiology, Manchester, 84, 1986.
4. Scanning electron microscopy of cryofixed Sitka spruce mycorrhizas: a comparison with critical point-dried material. By Clare Alexander, D. Jones and W.J. McHardy. Submitted to *New Phytologist*.
5. SEM of cryofixed mycorrhizas. By D. Jones, Clare Alexander and W.J. McHardy. Abstract P.M3-1, 14th International Congress of Microbiology, Manchester, 149, 1986.
6. Scanning electron microscopy of cryofixed mycorrhiza of Sitka spruce (*Picea sitchensis*) and other selected mycological specimens. By D. Jones, Clare Alexander and W.J. McHardy. *Proceedings of the Royal Microscopical Society* 21, S87, 1986.
7. Scanning electron microscope and X-ray powder diffraction of crystals of the macrolide dilactone antibiotic, vermiculine, accumulating in shake cultures of *Talaromyces wortmannii*. By D. Jones and M.J. Wilson. To appear in *Transactions of the British Mycological Society*.
8. Characterization of crystals of vermiculine from shake cultures of *Talaromyces wortmannii*. By D. Jones, M.J. Wilson and J.D. Russell.

Abstract P.G4-2, 14th International Congress of Microbiolgy, Manchester, 245, 1986.

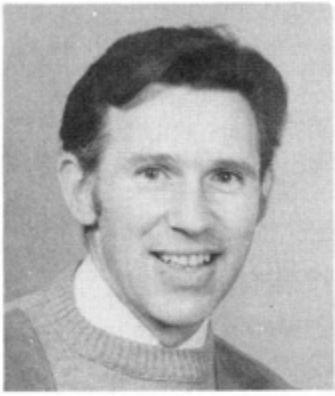
9. 5-hydroxymaltol, a secondary metabolite from *Penicillium echinulatum* Fassatiova spec. nov. By D. Jones, H.A. Anderson, J.D. Russell, A.R. Fraser, A. Hepburn and A.H.S. Onions. Abstract P.G4-1, 14th International Congress of Microbiology, Manchester, 245, 1986.
10. A natural direct effect of microorganisms on soil structure development. By R.E. Wheatley and M.V. Cheshire. Abstract P.B28-3 14th International Congress of Microbiolgy, Manchester, 13O, 1986.
11. Carbon and nitrogen in the soil microbial biomass associated with a spring barley crop. By K. Ritz and D. Robinson. Abstract P.G8-11, 14th International Congress of Microbiology, Manchester, 284, 1986.
12. Inoculum in the fumigation method for soil biomass determination. By S.J. Chapman. To appear in *Soil Biology and Biochemistry*.
13. Microbial sulphur in some Scottish soils. By S.J. Chapman. To appear in *Soil Biology and Biochemistry*.
14. Microbial biomass sulphur in some Scottish soils. By S.J. Chapman. Abstract P.G8-1, 14th International Congress of Microbiology, Manchester, 283, 1986.
15. Effects of carbon amendment of nitrate additions to sandy soil upon leaching of nitrate, microbial predator populations and uptake of nitrogen by ryegrass plants. By K. Ritz and B.S. Griffiths. Submitted to *Plant and Soil*.
16. Mineralization of nitrogen and phosphorus by mixed cultures of the ciliate protozoan, *Colpoda steinii*, the nematode *Rhabditis* sp. and the bacterium, *Pseudomonas fluorescens*. By B.S. Griffiths. To appear in *Soil Biology and Biochemistry*.
17. Growth of selected microorganisms and plants in soil sterilised by ethylene oxide or gamma-irradiation. By B.S. Griffiths. To appear in *Soil Biology and Biochemistry*.
18. Interactions between nematodes, ciliates and ryegrass under different moisture regimes. By B.S. Griffiths. Submitted to *Soil Biology and Biochemistry*.
19. Digestion and excretion of nitrogen and carbohydrate by the cranefly larva, *Tipula paludosa* (Diptera, Tipulidae). By B.S. Griffiths and M.V. Cheshire. To appear in *Insect Biochemistry*.
20. Microorganisms associated with the hindgut of *Oniscus asellus* (Crustacea, Isopoda). By B.S. Griffiths and S. Wood. *Pedobiologia*, 28, 377-381, 1986.
21. Endosymbionts associated with the hepatopancreas of the terrestrial isopods *Oniscus asellus* and *Porcellio scaber*. By S. Wood and B.S. Griffiths. Abstract. P.G2-27, 14th International Congress of Microbiology, Manchester, 234, 1986.
22. On the nature of calcium in the exoskeleton of the woodlouse, *Oniscus asellus*. By S. Wood and J.D. Russell. To appear in *Crustaceana*.
23. The decomposition of the exoskeleton of the terrestrial isopod

Oniscus asellus and the microbial deposition of calcite in soil. By S. Wood, M.S. Davidson and J.D. Russell. Abstract P.G2-26, 14th International Congress of Microbiology, Manchester, 234, 1986.

24. Rates of denitrification in reseeded blanket bog peat. By R.E. Wheatley and B.L. Williams. Abstract P.G8-12, 14th International Congress of Microbiology, Manchester, 284, 1986.
25. Biomineralization in crustose lichens. A Review. By D. Jones and M.J. Wilson. In *The Systematics Association Symposium on Biomineralization in Lower Plants and Animals*, Edited by B.S.C. Leadbeater and R. Riding, Oxford University Press, Oxford, 91-105, 1986.
26. Lichens and Pedogenesis. By D. Jones. To appear in CRC Handbook of Lichenology.

7. SOIL FERTILITY

D. Atkinson



The overall objective of the Department's research programme is to increase understanding of the ways in which soil factors, chemical, physical and biological, influence the performance of crops. During the current year the changes in the department's research programme identified in the 1985 report have continued: studies of crop root system development and activity are increasingly being used to understand soil-nutrient-plant interrelationships. The practical aim of this approach is an improvement in the efficiency of the use of fertilisers and other agrochemicals and more effective soil exploitation by crops. These aims are increasingly set against the need to minimize any adverse environmental impact, e.g. nitrate losses to ground water in the nitrogen programme. The department continues to have both studies on specific disciplines, e.g. the chemistry of sulphur in soils and more integrated projects, e.g. improved potato culture. Concern about surpluses of cereals within the EEC has lead to a major rethink within the department about objectives and stressed the need for alternative cropping enterprises. As a consequence an institute-wide group has met several times in 1986 to plan a future research programme on Agro-forestry. Jointly with the Hill Farming Research Organisation the institute has shared an increased flexibility award to help develop research in this area. Studies on the culture of broad-leaved trees began in 1986. This is expected to develop into a major research programme.

In December 1985 the Department of Agriculture and Fisheries for Scotland published its paper "Strategy for Agricultural Research and Development". This suggested the transfer of staff concerned with and work on arable soil fertility and crop nutrition to the Scottish Crop Research Institute, the transfer of specialist soils advisory work and the responsibility for providing an advisory soil analysis service to the Scottish Agricultural Colleges and the amalgamation of the remainder of the institute with the Hill Farming Research Organisation. In addition, reductions in finance for agricultural research have resulted in staff redundancies. These changes, due to be implemented in 1987, have had a major impact on the department as its staff is to be divided between 3 organisations. Most of our current research programmes and groups are of recent duration and have only recently begun to produce results and so these changes are a matter of regret. However the effective way in which staff have continued to tackle their research objectives during what has been a difficult year gives great confidence for the future.

During the year contacts with the Scottish Agricultural Colleges,

particularly the North of Scotland College of Agriculture (NOSCA), have increased and developed. In November the institute and NOSCA jointly organised a farmers' subject day on "Optimizing Returns from Nitrogen". This very successful event was held in the new Aberdeen Conference Centre. Dr D. Atkinson and Dr P. Millard represented the institute on the organising committee. Agricultural soil testing has continued. During the year the Scottish Soil Fertility Information System, which unites our data with that from the East of Scotland and West of Scotland Colleges of Agriculture was established. The first report summarizing Soil Fertility data on an all Scotland basis is expected shortly. Members of staff continue to be actively involved with the MISR/COSAC Liaison Committee. Dr A. H. Sinclair is chairman of the group's working party on the Scottish Soil Fertility Information System and on Soil Advisory Analyses. Dr P. W. Dyson is chairman of the SARI/COSAC committee on Maximum Yields and Yield Constraints — Cereals.

The emphasis on departmental staff attending agricultural and horticultural meetings has continued. The department was represented at the Royal Show (held at the National Agricultural Centre, Stoneleigh, Warwickshire) by an exhibit on the importance of Nitrogen supply for potato growth and quality. The same exhibit formed the basis of the institute's presentation at the Aberdeen Horticultural Society's summer show. A technical note 'The influence of nitrogen supply on potato yield and quality' was distributed at both events[1]. During the year Dr D. Robinson gave a series of lectures sponsored by the Botanical Society of Edinburgh at 6 Scottish Universities on 'The significance of the nitrogen-cycle in plant ecology'. Dr D. Atkinson visited Michigan State University to teach at their annual Farmers' Fruit School and was the guest speaker at the West Virginia State Horticultural Society[2,3].

Collaborative programmes of research with other institutes have continued. Studies with the Rowett Research Institute and NOSCA on the effects of feeding ammonia-treated straw to stock have been developed while those on the effects of feeding sulphur-deficient grass have continued[4]. The collaborative programmes with the Scottish Crop Research Institute (SCRI) on the potato crop have been increased with two collaborative papers being published[5,6].

A number of members of staff are involved in the organisation of meetings for scientific societies and in the editing of journals. Dr D. Atkinson is vice-chairman of the programme committee for the 1987 British Crop Protection Conference — Weeds while Dr D. Robinson and Dr D. Atkinson are part of a group organising, for the British Ecological Society, a major international meeting on plant root systems. Dr A.H. Sinclair continues as editor of Norgrass while Dr D. Atkinson serves on the editorial boards of "Plant and Soil", "Tree Physiology" and "Communications in Soil Science and Plant Analysis".

Staff turnover has been much less of a problem in 1986. In February we were pleased to welcome Dr A. Edwards who joined the department from the University of Aberdeen to work on soil acidity and phosphate nutrition. During the year the department has received a number of short and longer-

term visitors. Professor A.J.M. Smucker from Michigan State University paid a short visit to help develop the department's interests in the use of minirhizotrons. Mr Peter Mortimer from Liverpool Polytechnic has been working as a sandwich student financed by the Sulphur Institute. Dr Gerry Neilsen and Dr Denise Neilsen from Agriculture Canada, British Columbia, are on one-year's sabbatical leave to work respectively on tree root development in acid soils and micronutrient mobilisation at the soil-root interface. Ms. Katherine Kaye from the University of Oxford has been working on sulphur and selenium in both herbage and soils as part of her investigations of forage quality in the Western Isles. Mr G.D. Wimaladasa from the Tea Research Institute of Sri Lanka has joined the department for three years to work for a PhD degree on factors affecting potassium supply from soils.

Crop Physiology and Nutrient Supply

Studies in crop physiology aim to understand the ways in which mineral nutrients, which are often added as fertilisers, e.g. nitrogen, sulphur, influence crop growth and food and fodder quality.

Nitrogen

Nitrogen remains the largest variable input into most crops and hence studies aim to understand its fate in the soil, factors influencing its absorption by plants and the mechanisms by which it affects yield and quality. An understanding of these factors is seen as the best way of meeting the agriculturalist's needs for optimum production and the conservationist's demands for reduced environmental contamination. A paper on nitrogen losses from catchments has been published[7].

Effects on Nitrogen Uptake and Partitioning by the Potato Crop. Many annual plants use nitrogen which was first assimilated during vegetative growth for reproduction. Their nitrogen economy can, therefore, be considered as a conflict between the need for producing vegetative (capital) and reproductive growth[8]. Field experiments have shown that the rate of nitrogen uptake by the potato crop decreases during the second half of the season[5]. This occurs around the time when the nitrogen content of the canopy reaches a maximum. Thereafter, there is a decline in the amount of nitrogen in the canopy, due to the senescence and abscission of the lowermost, shaded leaves, and a redistribution of nitrogen to the growing tubers[6]. Nitrogen used for tuber growth can, therefore, originate from stored nitrogen redistributed from the canopy, or from that absorbed from the soil, transported to the leaves as nitrate, then reduced and re-translocated to the tubers. Table 7.1 shows that stored nitrogen contributes substantially to tuber growth in both nitrogen-deficient and replete plants.

To distinguish between the use of currently assimilated and stored nitrogen for reproductive growth, a method has been developed whereby a

TABLE 7.1 The potential contribution of soil nitrogen and that stored in the canopy (kg ha^{-1}) to the nitrogen used in the reproductive growth of potatoes (kg ha^{-1}) during the later half of the season. Data are shown for crops grown with contrasting rates of nitrogen fertiliser (kg ha^{-1})

N application rate	Increase in tuber N	Potential contribution to tubers from: Soil	Leaves	Stems
0	35	23	10	2
240	106	61	45	0

pulse of ^{15}N can be applied to a plant[9] (see also p 176–8). Soon after emergence of the potato plant, soil from half the drill is removed and replaced by a polyacrylamide gel/sand mixture containing slow release fertiliser. Roots grow into this medium and later in the season can be isolated by washing away the gel/sand mixture with water (Figure 7.1).

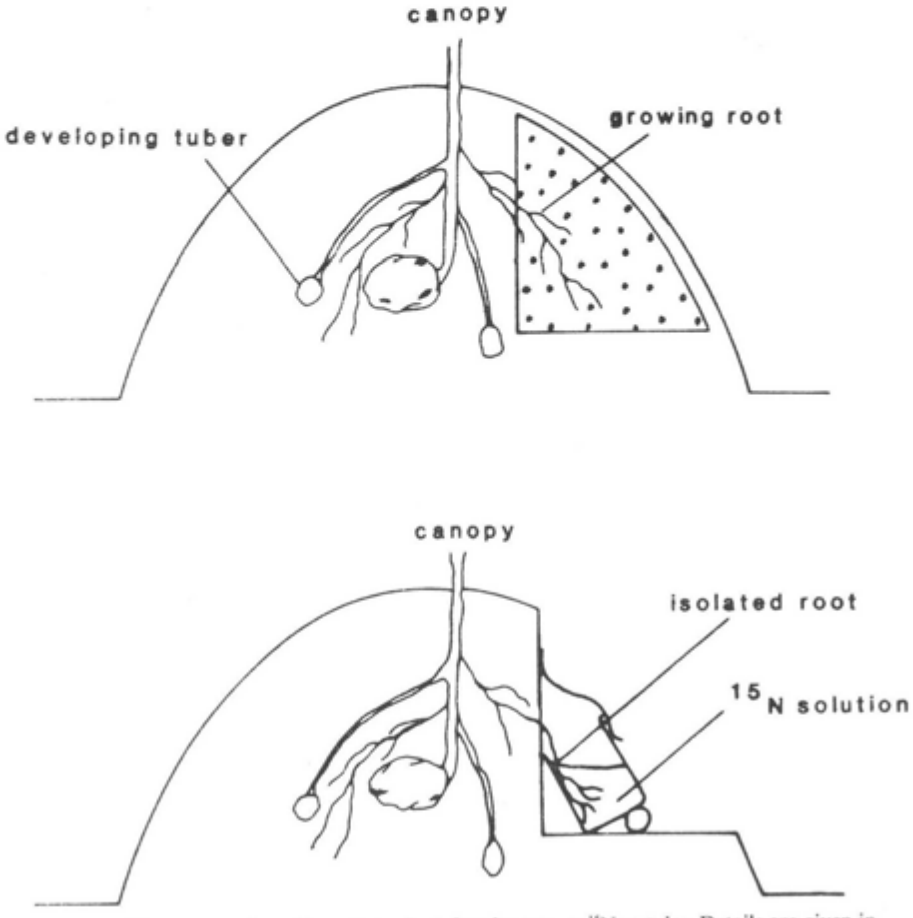


Figure 7.1 The preparation of a potato plant for short-term ^{15}N uptake. Details are given in the text

Isolated roots are then immersed in $^{15}NH_4$ $^{15}NO_3$ solution for 24h and the subsequent distribution of ^{15}N throughout the plant monitored after suitable "chase" intervals. The technique has been applied in a field experiment where plants were supplied with either no nitrogen fertiliser or 200 kg N/ha. Plants were pulsed with ^{15}N for 24h on three different occasions during the growth of the crop and harvested after various chase periods, right up to the final harvest. Analysis of ^{15}N uptake has shown that net nitrogen fluxes into the root were similar throughout the season. Roots clearly retain a considerable physiological capacity to absorb nitrogen during the later part of the season when the rate of nitrogen uptake by the crop is declining (see also p 178). Further analysis of ^{15}N partitioning within the plant is currently being made. 7039, 7047

Plants can take up nitrogen faster than is needed for current growth. This luxury consumption results in accumulation in the tissues. Nitrogen can accumulate as either nitrate or reduced nitrogen, eg amino acids and proteins. Nitrogen accumulation in the potato crop has been studied in two field experiments. Here the largest accumulated nitrogen pool was as soluble proteins in the canopy. Amounts of nitrate and free amino acids were smaller[5]. In many plants Ribulose 1,5 biphosphate carboxylase/oxygenase (RUBISCO), is quantitatively the most important leaf protein. It can accumulate in response to luxury nitrogen uptake and so may be used as a nitrogen store[8].

Over half the total protein-nitrogen accumulating in leaves, as a consequence of an increased nitrogen supply, could be accounted for by increased RUBISCO concentrations (Table 7.2). Towards the end of the season there was as much nitrogen accumulated as RUBISCO, as was recovered in nitrate. Within the canopy, RUBISCO concentrations were found to be greatest in the unshaded leaves at the top of the stem. The plant, therefore, appears to distribute RUBISCO so as to maximise carbon gain. The concentrations of RUBISCO were measured using polyclonal antibodies in a collaborative study with the Institute of Animal Physiology. It is hoped to use the ^{15}N pulse-chase method of labelling plants (Figure 7.1) to monitor the partitioning of nitrogen into RUBISCO at different stages of crop growth and directly to assess its potential as a nitrogen store in potato leaves. 7047

A mechanistic understanding of the partitioning of nitrogen within the potato crop needs the relationship between the supply of nitrogen from the

TABLE 7.2 The concentrations of nitrogen (mg g^{-1} DM) accumulating in different forms in potato leaves, as a consequence of increasing nitrogen applications to the crop from 0 to 250 kg N ha^{-1}.

	Days after crop emergence		
Component	38	68	80
Free amino acids	2.9	2.6	0.9
Nitrate	6.3	5.9	5.9
Protein	7.5	7.3	9.0
RUBISCO	4.3	4.0	5.8

soil and the demand for nitrogen by the plant to be quantified. To do this a large, multidisciplinary experiment assessing nitrogen cycling in the soil-plant system has been conducted. Two treatments, no nitrogen, or 200 kg N ha^{-1}, were applied to potatoes and soil nitrogen cycling, microbial biomass, plant growth, root-system development, nitrogen uptake and partitioning within the plant measured. ^{15}N labelled fertiliser was used to follow the fate of applied fertiliser. The many data from this trial are still being processed.
7047, 7044, 7039, 6027

Radiometry. Studies on crop reflectance properties have continued in collaboration with the Department of Peat and Forest Soils. Changes in the reflectance ratio of the potato crop, post canopy closure, appear to be related to canopy structure and chlorophyll content[10]. A sealed standard method for the determination of chlorophyll has been developed. The method uses a liquid scintillation counter as a spectrometer. A sealed 5 ml vial containing about 1000 becquerals of ^{14}C hexadecane in a toluene based scintillator is placed in a 20 ml polythene scintillation vial. To the outer vial 15 ml of a dimethyl sulphoxide extract of potato leaves is added and counted. The quenched count rate relates to the amount of chlorophyll present. The seasonal changes are shown in Table 7.3. The weekly chlorophyll measurements from each plot in the multidisciplinary potato experiment are being related to frequent radiometric readings and the data used to study the relationships between nitrogen nutrition, crop reflectance and crop growth throughout the season. 7047, 7049

Effects on Growth and Quality in Potato. Nitrogen fertilisation increases the yield of the potato crop by increasing light interception during the first part of the season, and causing a delay in canopy senescence during the later part[5]. A late application of nitrogen will, therefore, help delay canopy senescence and be beneficial to a ware crop. However, most of the nitrogen taken up by the crop is assimilated during the first part of the season (Figure 7.2). Dividing the dressing of fertiliser, and applying half at planting and half at tuber initiation had no significant effect upon tuber yields (Table 7.4). 7047

Ammonium Nitrate and Urea Fertilisers: recovery by a potato crop. The relative merits of ammonium nitrate and urea as nitrogen fertilisers are currently the subject of debate. Ammonium nitrate is available to a crop almost immediately after application while urea must be hydrolysed in the soil to release ammonium which is then nitrified to nitrate. Ammonium nitrate contains 35% nitrogen by weight, compared with 47% in urea. The

TABLE 7.3 Variation in the chlorophyll levels ($\mu g\ mg^{-1}FW$) of potato leaves grown with 200 kg ha^{-1} nitrogen or no nitrogen (control)

Treatment	Date						
	1 Jul	15 Jul	22 Jul	5 Aug	19 Aug	9 Sept	29 Sep
Nitrogen	1.06	1.65	2.30	1.74	1.81	1.73	1.48
Control	0.85	1.25	1.62	1.19	1.43	1.23	0.62

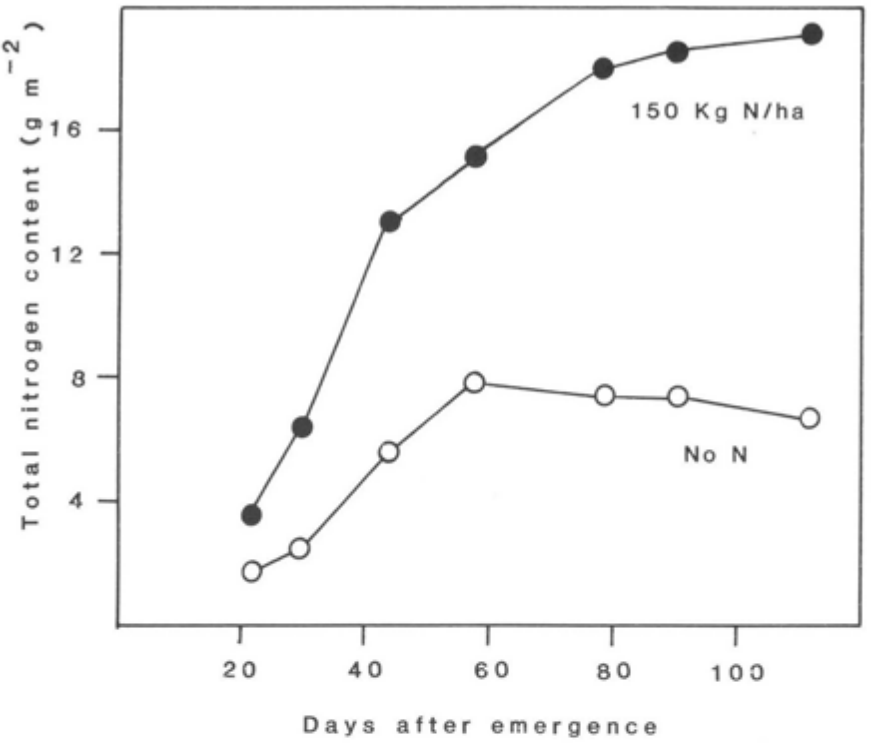


Figure 7.2 The uptake of nitrogen by a potato crop grown with either no nitrogen or 150 kg N ha^{-1} applied at planting

TABLE 7.4 The effect of a split, compared to a single application of nitrogen (kg ha^{-1}) on potato yield (Mg (tonnes) ha^{-1})

Nitrogen application		Yield
At planting	At tuber initiation	
100	-	52.1
50	50	53.4
200	-	53.8
100	100	56.7
150	-	56.9

initial build-up of nitrate in the soil with ammonium nitrate makes some losses by denitrification and leaching more likely. Currently urea is marginally cheaper but with it some loss, especially on dry, chalky soils, is likely due to the volatilization of ammonia. Many field trials have shown a slight (often non-significant) yield loss with urea when compared with crops supplied with ammonium nitrate.

In 1985, the efficiency with which fertiliser nitrogen is recovered by a crop was assessed. Ammonium nitrate was applied at planting, at 80 or 120 kg N ha^{-1}. The same rates were used in two further treatments but here half

the nitrogen was applied as ammonium nitrate at planting and half as urea as a series of four foliar sprays, the first at tuber initiation and thereafter at fortnightly intervals. At both of the rates of nitrogen application tested, the foliar spray increased yields (Table 7.5). The increases however were only found at the end of the season and in the ware fraction.

Both the ammonium nitrate and urea were applied labelled with ^{15}N (*ca* 1 atom % excess abundance) to allow the efficiency of fertiliser nitrogen uptake to be measured. The recovery by the whole crop of ammonium nitrate-N was greater at the higher rate of application. Recoveries in the tubers were identical (Table 7.6). In contrast, the recovery of foliar applied urea-N in the tubers was significantly greater than for ammonium nitrate. Recovery was greater at the lower rate of application.

The direct application of nitrogen to the foliage reduces the amount entering both the soil and the crop roots, although some uptake by this route must have occurred. 1985 was a very wet year and some of the spray was washed from the foliage soon after application. Foliar application can supply nitrogen to the crop when it is needed for growth. Soil applications need to be applied at planting which is before there are roots present and at a time when losses by leaching, denitrification and immobilization are likely. These losses reduce the recovery of soil-applied nitrogen fertilisers. Aligning fertiliser supply more closely to crop demand may improve the efficiency of recovery. 7039, 7047

Rate Responses in Winter Wheat. Experiments carried out in 1986 support the current NOSCA/MISR recommendation that 180 kg N ha^{-1} is required for winter wheat. The main objective of 1986 trials was to test the theory that the main nitrogen dressing(s) for wheat should be applied at the terminal spikelet stage. The case for this is based on evidence, mainly from the south-east of England, that tiller survival is enhanced by N applied at this stage. Three trials tested the effects of seven dates of N application spaced at weekly intervals and spanning the terminal spikelet stage. In two trials, rates of 130, 160 and 190 kg N were compared while the third compared 130 and 190 kg N ha^{-1}. 30 kg N ha^{-1} was applied at the double ridge stage in all trials.

There were no significant interactions between amount and time of N application. Figure 7.3 shows the effect of variation in time of N application on grain yield averaged over all rates of N. There were no consistent differences in yield following N application up to 2 to 3 weeks before the terminal spikelet stage compared to applications at or about that

TABLE 7.5 The effect of a foliar application of nitrogen (kg ha^{-1}) as urea or ammonium nitrate on the yield (Mg (tonnes) ha^{-1}) of potatoes

Nitrogen application		Yield
At planting	foliar spray	
80	-	57.4
40	40	62.0
120	-	59.0
60	60	63.0

TABLE 7.6 Efficiencies of fertilizer nitrogen recovery by a potato crop. Values for urea refer to the percentage of foliar urea recovered.

N source	Application rate (kg N ha^{-1})	% fertilizer N recovered in: whole crop	tubers
Ammonium nitrate, all at planting	80	49	37
	120	56	38
"Urea", 50% as foliar spray	80	68	57
	120	53	42

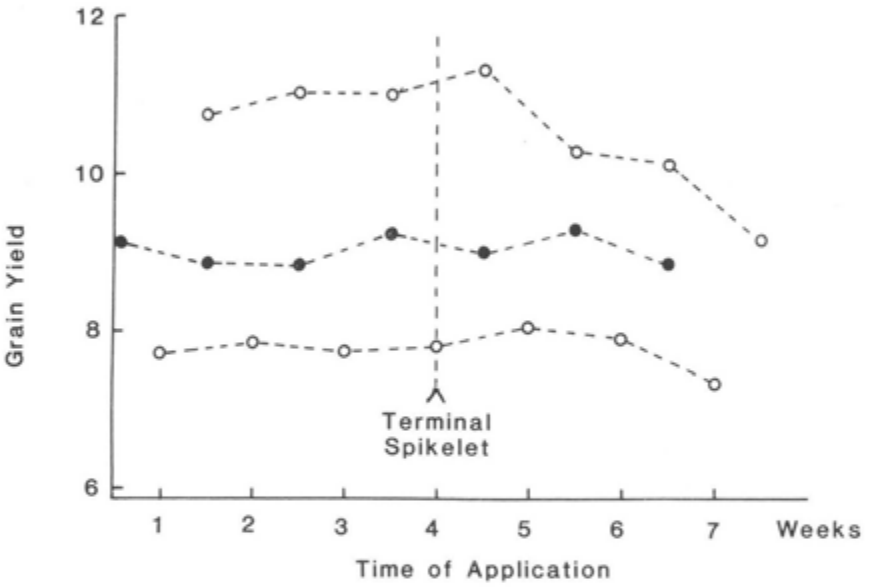


Figure 7.3 The effect of date of nitrogen application on the yield (Mg (tonnes) ha^{-1}) of winter wheat

stage. Applications delayed by more than a week after terminal spikelet had little detrimental effect on yield in the two lower yielding crops, but substantially reduced yield in the high yielding (>11 Mg ha^{-1}) crop. Growth, development and nutrient uptake were measured at 2-3 week intervals on these trials. When these data are processed they should allow detailed comparison with results obtained elsewhere in the U.K., especially of the effect of N timing on patterns of tiller production and survival. Limited results from the rather atypical 1985 season suggest that in the north-east of Scotland there are fewer tillers, but ultimately more ears, than in the south-east of England. 7048.

Rate Responses in Winter Barley. Current recommendations for the timing of N supply to winter barley (SAC/MISR publication no. 160)

TABLE 7.7 Effect of split nitrogen dressing on the yield of winter barley

Total N applied mid April (kg ha^{-1})	Grain yield Mg (tonnes) ha^{-1} Top dressings applied (40 kg ha^{-1})			
	Nil	Early 12 March	Late 26 May	Early + Late
140	9.04	8.83	8.63	8.69
180	9.31	9.16	9.03	8.77
220	9.10	9.36	9.59	9.23
260	9.35	9.33	9.60	9.33
			S.E. 0.19	

suggest that part of the N should be applied at the start of spring growth and part at the beginning of stem extension. The objectives of this are 1) to ensure that N supply is not limiting in the early spring, so allowing rapid canopy closure, and 2) to ensure that the supply is maintained in the later stages of growth. In practice many farmers apply small (20-40 kg N ha^{-1}) supplements at earlier and later stages.

Two experiments were conducted to test the efficacy of these practices on both early and late sown crops. An 'early' application of 40 kg N ha^{-1} was given on 12 March when one experimental crop was at the 2-3 leaf stage and the other at the 5-6 leaf stage. The 'late' application consisted of 2 sprays of urea, a total of 40 kg N ha^{-1}, at flag leaf emergence. The 'main' N dressing was given as a single application in mid April to give total N inputs of 140, 180, 220 and 260 kg N ha^{-1}. The responses to N were very similar at the two sites and so combined results are shown in Table 7.7. With total N inputs of 140 or 180 kg N ha^{-1} a single application was at least as effective as the same amount split into two or three applications. At higher total rates of input there was a small, non-significant, increase in yield when 40 kg N ha^{-1} was applied late. The prolonged cold weather in spring may have limited the response to the early application of N. In these trials the 'main' N dressing was applied as a single application rather than the recommended 50:50 split, in order to accentuate possible responses to the early and late applications. However, results do not suggest that consistent benefits are likely to accrue as a result of these practices. 7048

Sulphur

Low atmospheric inputs and purer phosphate fertilisers together with small amounts of available sulphate in some soils make sulphur deficiency a particular problem in the north of Scotland. Trials continue to explore its effects on the quality of fodder and probable effects on ruminants, means of alleviating deficiency and its relationship with soil type.

Effects on Grass Quality. Work, in collaboration with the Rowett Research Institute, on the influence of sulphur deficiency on grass composition and its effects on degradation in the rumen has continued. Grass was grown on an Auchenblae soil, which is low in plant-available sulphur, with or without 40 kg ha^{-1} sulphur application. Herbage from the second cut was fed to sheep and degradability experiments were performed

TABLE 7.8 The uptake of sulphur (kg ha^{-1}) by oilseed rape, measured at flowering

Sulphur application (kg ha^{-1})	Nitrogen application (kg ha^{-1})		
	100	150	200
0	21.9	20.2	22.0
20	34.8	33.1	36.7
40	31.2	41.5	48.8

in sacco . Sulphur-deficiency decreased the concentration of lignin in the grass but increased its dry matter and cellulose degradability. Feeding sulphur-deficient grass supplied a maximum of 0.6 g S $animal^{-1}$ day^{-1} compared to 2.0 g with the fertilised grass. The former was insufficient to meet the sulphur requirements of the rumen microbes and so reduced their ability to degrade the grass. Crude protein degradabilities can be decreased by feeding diets low in sulphur and so the loss of individual amino acids from the grass was measured by hydrolysis and amino acid analysis of rumen-incubated residues. The changed composition of the grass, in response to fertiliser sulphur application decreased the loss of aspartic acid from the samples, probably due to a decreased loss of free asparagine, which accumulates in sulphur-deficient grass. In contrast, reducing the sulphur-status of the rumen resulted in a reduced loss of most amino acids, indicating a reduction in protein degradation[4]. Feeding sulphur-deficient grass reduced the ability of rumen microbes to degrade protein and fibre and so samples of rumen fluid were recovered from sheep fed both types of grass and the composition of the microflora assessed. No detectable effect was found upon the numbers of viable or celluloytic bacteria, but changing the feed from the sulphur-replete to the deficient grass increased the numbers of celluloytic fungi recovered in the rumen fluid[4]. 7047

Effects on Oilseed Rape. A field experiment on an Auchenblae series soil with low S status (4 ppm extractable sulphate S) assessed interactions between nitrogen and sulphur. There was a linear increase in seed yield in response to nitrogen over the range 100-200 kg N ha^{-1}. In contrast, soil application of micronised elemental S at 20 or 40 kg S ha^{-1} had no effect on yield. In previous years this soil had shown substantial increases in the yield of ryegrass with additions of 10-20 kg S ha^{-1}. Sulphur applications however increased the sulphur content (Table 7.8). The lower rates of nitrogen however limited sulphur uptake .

A second experiment at the same site assessed the effect of the timing of sulphur application. Yield and sulphur uptake were not affected by whether sulphur was added as a split application (10 kg S ha in autumn and remainder in spring) or as a single addition in the spring. 7038

Effects of Form of Sulphur on Response in Grass. The efficacy of different forms of sulphur in alleviating sulphur deficiency in ryegrass grown on a low S soil was assessed in a pot experiment. Compared to a No-S control large responses were obtained with all forms of added sulphur

TABLE 7.9 The effect of the form of sulphur on the response of ryegrass (g per pot): total from 4 cuts

Sulphur form	Yield
Control- no sulphur	22.2
Micronised elemental S as "Thiovit"	58.4
Micronised elemental S as "Kumulus"	54.8
Micronised elemental S as "Supersix"	56.6
Ammonium thiosulphate	58.6
A mixture of ammonium sulphate, sodium sulphate and elemental S as "Tracey 3S"	57.2
Potassium sulphate	58.9

(Table 7.9). Under the conditions of the pot trial none of the different types of sulphur conferred any yield advantage over the others. Foliar application of three different forms of micronised elemental S (thiovit, kumulus, supersix) behaved similarly. Application one week after the first cut gave subsequent yields of 49.8, 53.0 and 51.8 g respectively. Early diagnosis of sulphur deficiency and remedial action are essential if this type of treatment is to be fully effective. 7038

The Fate of Micronised Elemental S. Micronised elemental sulphur was applied as thiovit to peas (*Pisum sativum*). Studies utilized the argenteum mutant(produced by Geneva Research Station, New York State), which allows the physical fractionation of the leaves. Image analysis of sprayed material indicated that most of the sulphur microballs were within the specified 1-8 μm range but that there were some larger particles present. Studies using the scanning electron microscope and a cold stage has confirmed that almost all particles on the leaf surface were within the designated size range although a substantial amount of aggregation on the leaf surface had taken place. Micrographs of field-grown plants taken 3 hours and 5 days after spraying have shown the effect of weathering on the sulphur microballs (Figure 7.4). After a 5 week period, no traces of the sulphur application remained. In contrast, sulphur could still be detected on the leaf surface of a plant grown under glass after 10 weeks (Figure 7.4) 7038

Trace elements

Copper and Zinc Binding by Straw. In collaboration with the Rowett Research Institute, North of Scotland College of Agriculture and the Department of Spectrochemistry (see also page 78) the effect of ammonia treated cereal straws on nutrient content and acceptability to ruminants has been assessed. The short lived isotope^{64} Cu which has a half life of 12.8 hours was used to determine the ability of ammonia treated and untreated wheat and barley straws to absorb copper under conditions similar to those existing in the rumen. 5 g of straw were shaken with 100 ml of a labelled copper sulphate solution (3 mg Cu/kilo straw) at 35°C. The results, which were similar for both sets of straws, showed very rapid adsorption with most copper removed from solution in the first hour (Figure 7.5). Binding

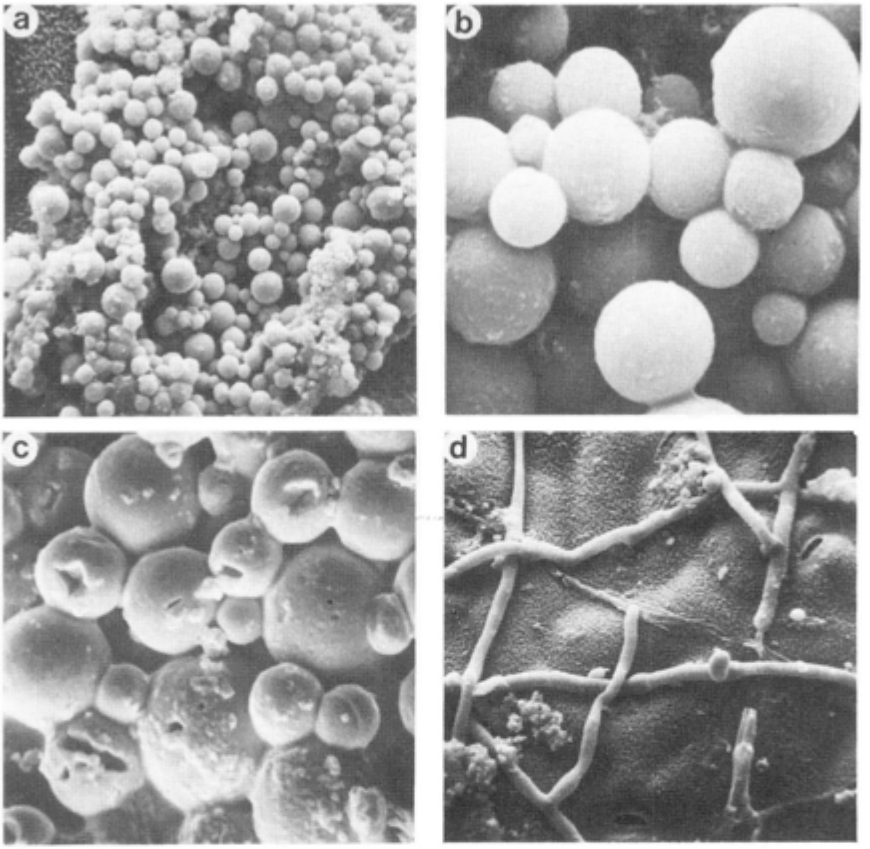


Figure 7.4 Scanning electron micrographs showing the appearance of sulphur microballs aggregated on leaf surface of P. Savitum (Argentum). a) After three hours (X1100), b) Sectional view at higher magnification (X5500), c) Five days later structures showing signs of degradation (X5500), d) Absence of sulphur and development of mildew after five weeks outdoors (X5500)

was higher in the ammonia-treated straws. Similar results were obtained with Zinc using ^{65} Zn. 7049

Soil Chemistry

The aim of these studies is to understand the soil chemical factors which influence the supply of both native and applied (fertiliser) nutrients to the soil solution around the plant root system and their equilibrium reactions with other soil constituents.

Arable Crop Rotations with Different Nutrient Inputs

Much of the current programme on soil chemistry involves a long term crop rotation experiment which was established at Cross of Jackston,

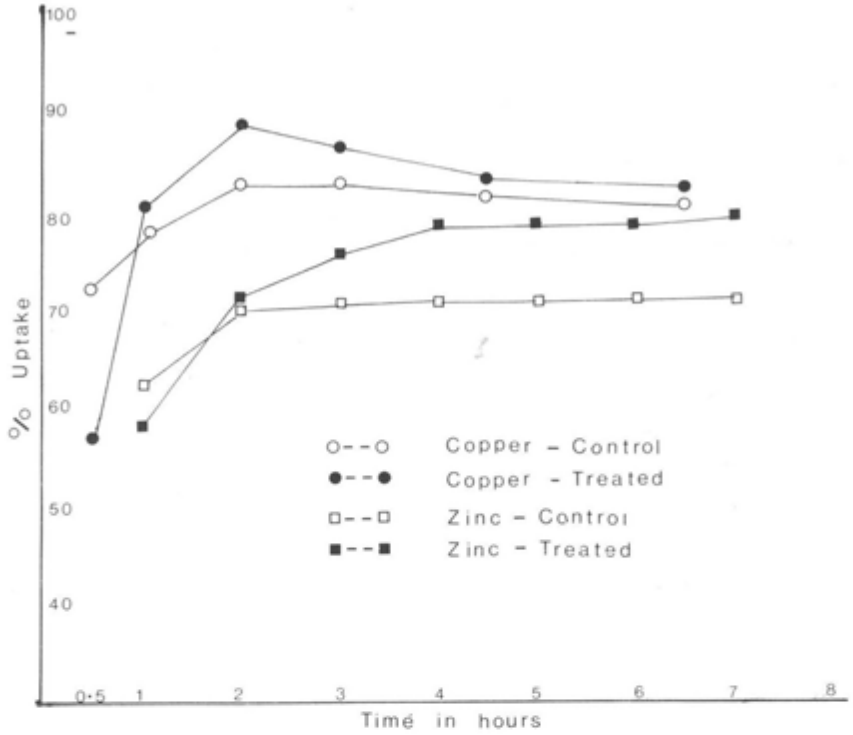


Figure 7.5 The binding of labelled copper and zinc by ammonia treated and control straw. Values are the means of data for wheat and barley straw

Aberdeenshire in 1983 (Report No. 53, p.105) where the effects of the various crops in the rotation on nutrient availability are being assessed.

Trial Design and Yield. Two crop rotations have been established on a soil of the Foudland series. One involves 3 crops of barley and two of grass with rates of nitrogen fertiliser. The other includes winter wheat, potato, spring barley and a grass clover ley. This trial includes plots receiving two different rates of nitrogen and sulphur and three rates of phosphate and potassium. The exact rates of application vary for the different crops in the rotation. Winter wheat receives nitrogen applications ranging from 100 to 160 kg ha^{-1}, phosphate from 25 to 50 kg, potassium from 35 to 70 kg and sulphur from 0 to 10 kg. Many of these treatments are factorially combined. There are also plots receiving farmyard manure (FYM) with and without the addition of other nutrients. Detailed appraisal of results will only be attempted at the end of the rotational cycles but early results show that yields are varying substantially between the FYM, standard (ammonium nitrate) nitrogen fertiliser and FYM + N plots. Mean yields (summed over the 3 years to date) show (Figure 7.6) that regardless of crop, yields were consistently highest with the higher rate of inorganic nitrogen and lowest with FYM. The different crops showed different relative responses to the

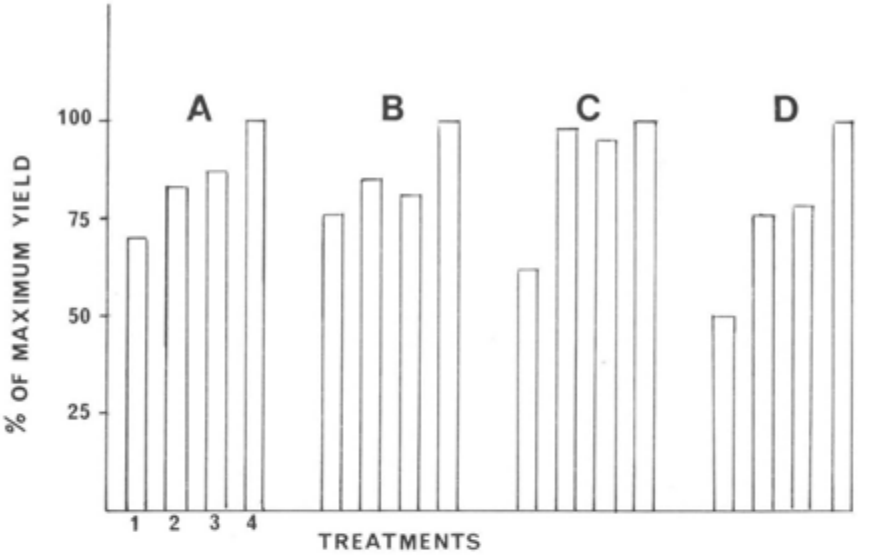


Figure 7.6 Comparison of FYM and nitrogen applications on summed yield over three years for each crop. A = Winter Wheat, B = Potatoes, C = Barley, D = Grass
Treatments 1 = FYM, 2 = FYM + N_1 3 = $N_1P_1K_1S_1$ 4 = $N_2P_1K_1S_1$

FYM and intermediate nitrogen treatments. Spring barley and grass grew least well with FYM. Growth of all crops with FYM + N (level 1) and a similar rate of nitrogen without FYM was similar. The general appearance of some of the plots in 1986 is shown in Figure 7.7. The responses of the various crops in the rotation to the individual nutrient treatments varies substantially.

Potassium. Soil samples from both the rooting zone (Report No. 55, p.142) and bulk soil and crop samples have been taken at 4 week intervals and exchangeable K^+, K concentration , pH, NO_3^-, NH_4^+, (Ca + Mg) and ionic conductivity measured. Root density is being measured at a number of depths to aid in the interpretation of soil and crop data.

Nitrogen Balance in the Barley/Grass Rotation. The nitrogen balance experiment was continued (Report No. 53, p. 105, 54, p. 118 and 55, p. 140) with measurements of soil and crop nitrogen contents, and their ^{15}N enrichments assessed throughout the year. In 1986, the variety of spring barley was changed from Golden Promise to Heriot in an attempt to overcome the problems with mildew which occurred in 1985.

Figure 7.8 shows the changes in soil nitrate under a first year barley crop which had received 125 kg N ha^{-1} as ammonium nitrate, and the amount of that nitrate derived from fertiliser; here this was applied labelled with ^{15}N. Initially, the soil contained 34 kg nitrate-N ha^{-1}. Application of the fertiliser (as a top-dressing at the two leaf stage, 37 days after sowing), increased it by a factor of three. Soil nitrate increased further to a maximum

Figure 7.7 The effect of FYM (R) and inorganic nitrogen (L) additions a) grass, b) potato

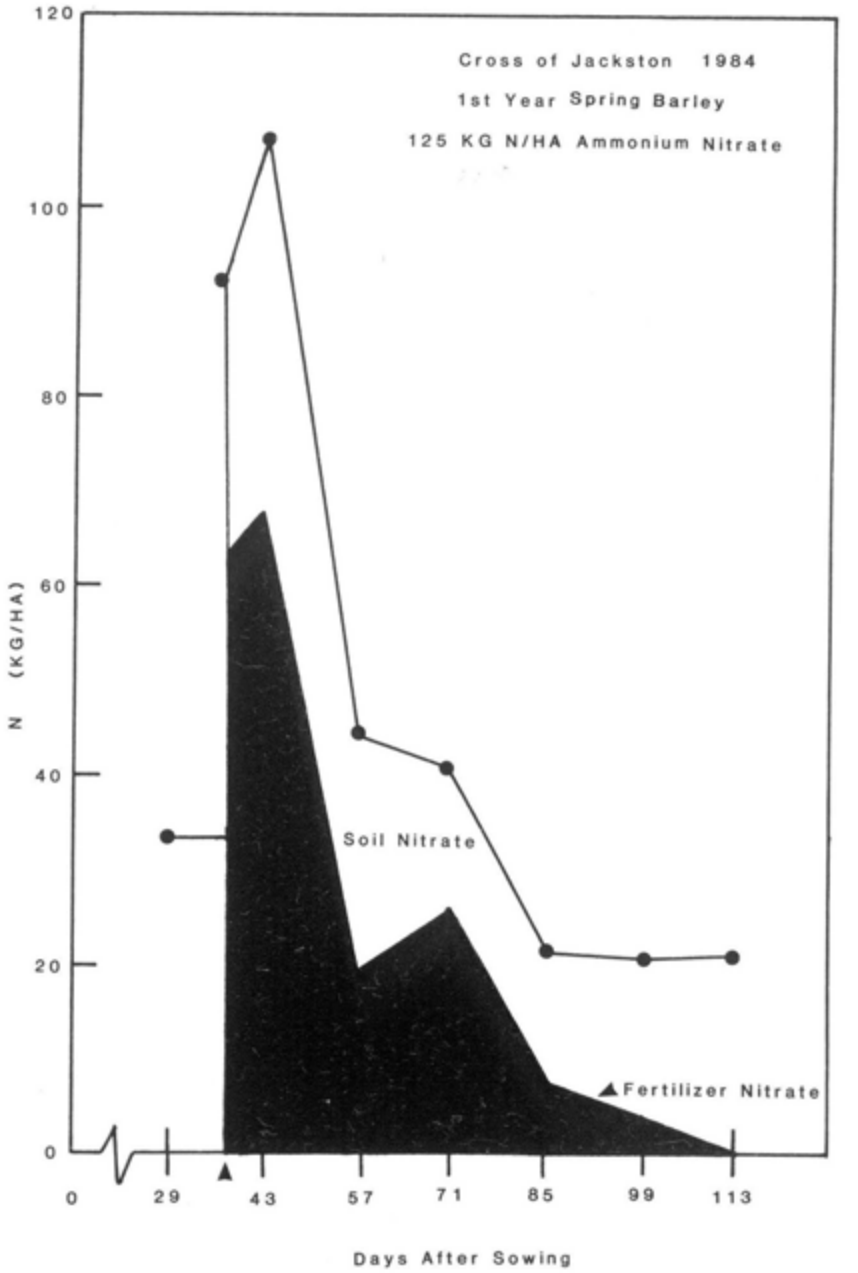


Figure 7.8 Changes in soil nitrate level beneath first year spring barley after grass at Cross of Jackston in 1984. The shaded part of the graph shows the contribution made by nitrate derived from the fertilizer.

TABLE 7.10 The effect of nitrogen form and liming on grass yield (averaged over 11 years) (Mg (tonnes) ha^{-1} DM)

	Nitrochalk	Urea	Ammonium sulphate
Limed	7.84	7.64	7.53
No lime	7.69	7.32	6.7

value of 108 kg ha^{-1} , 43 days after sowing, probably as a result of nitrification of the ammonium fertiliser exceeding uptake by the crop. Thereafter, as the rate of uptake and crop growth increased (Report No. 55, p. 138), the soil nitrate level declined, rapidly at first, and more slowly towards the end of the season. By the time growth and uptake had virtually ceased, soil nitrate appeared to have reached an equilibrium level of 20 kg N ha^{-1} of which none seemed to be derived from the fertiliser. As well as uptake of fertiliser nitrogen by the crop (*ca* 50% of that applied), there was a concurrent immobilization during the season of ^{15}N into non-exchangeable pools in the soil (mostly organic nitrogen). This accounted for *ca* 20% of the fertiliser applied. Some nitrate must have been lost by denitrification, possibly leaching and some would have remained in below-ground crop residues which were not removed from the soil for separate analysis.

Results for the 1985 and 1986 seasons are being analysed to see whether or not this pattern of the partitioning of fertiliser nitrogen is constant from season to season. The experiment is planned to continue until 1988. 7039

Soil Acidity

Soil acidity is of interest because, acid soils are common in Scotland, especially in the uplands, it has major effects on root development and greatly affects the availability and speciation of a number of trace elements. It is affected by a wide range of soil management practices including the form of nitrogen fertilizers applied.

Nitrogen Source and Acidity. Nitrogen as nitrochalk, urea or ammonium sulphate was applied, to give similar total amounts of N, to a long-term grass experiment. This also received large once-only applications of lime and/or phosphorus at the beginning of the experiment in 1968. The highest average annual yields of grass (2 cuts per year) were obtained with nitrochalk and in limed plots and the lowest with ammonium sulphate and in unlimed plots (Table 7.10). Ammonium sulphate caused a substantial reduction in soil pH of both limed, from 6.2 to 5.6, and unlimed plots, from 5.3 to 4.5. The other nitrogen treatments had little effect on soil pH (Figure 7.9). As a result of its effects on soil pH the ammonium sulphate treatment reduced the amount of acetic acid (0.43 m) extractable calcium (Figure 7.10). In the unlimed soil extractable calcium decreased gradually over 11 years from 80 mg 100 g^{-1} to 35 mg 100 g^{-1}. The limed plots showed little depletion until 1976 when there was a large fall. This delayed decline seemed related to the slow breakdown of the lime and the continued release of calcium.

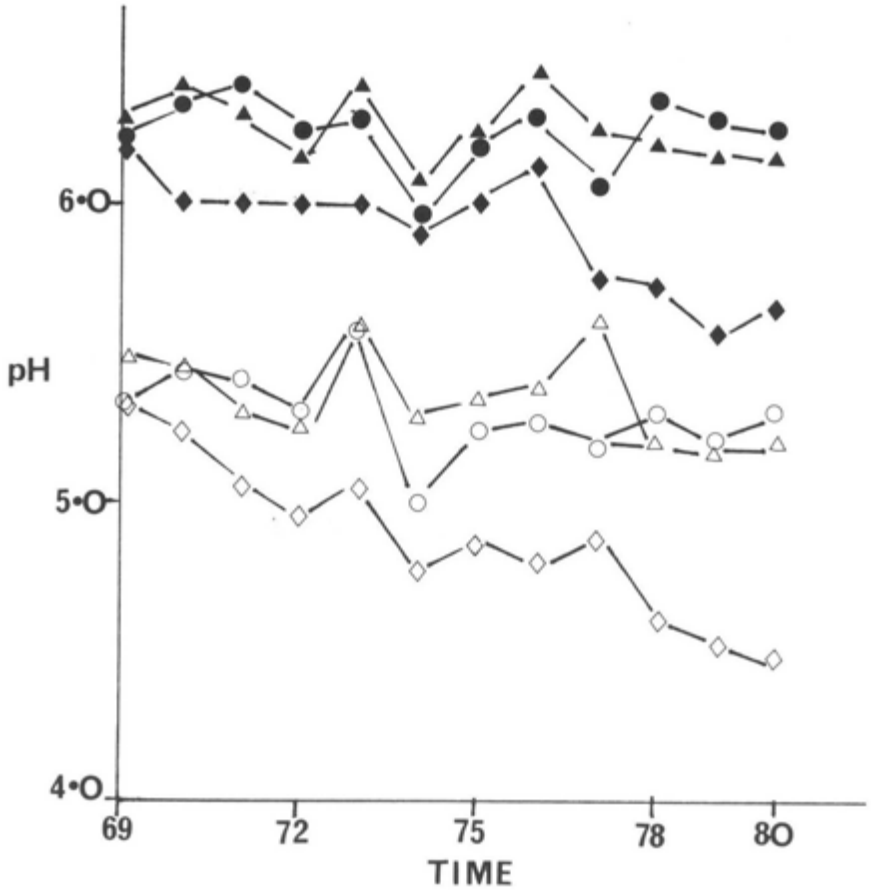


Figure 7.9 The effect of the form of nitrogen and liming on the soil pH of grass plots. Closed symbols limed, open unlimed ● ○ nitrochalk ▲ △ urea ◆ ◇ ammonium sulphate

Soil Acidity and Phosphorus. Results on the effect of soil acidity and phosphate fertiliser on the yield of spring barley and oilseed rape were published[11]. The yield of spring barley is reduced as soil pH drops (Table 7.11). Data represent mean yields of Golden Promise from three consecutive years. The reduction in yield was associated with the increasing solubility of soil aluminium. The soil contained 28 mg litre^{-1} of phosphorus, extracted by 0.43M acetic acid solution. Compared to 20 kg ha^{-1} a phosphate fertiliser rate of 60 kg ha^{-1} alleviated the effect of low soil pH on the yield. After three years with the higher rate, the soil phosphorus content had increased to 40 mg litre^{-1} compared to 31 mg litre^{-1} with the lower rate.

There was also an interaction between soil pH and phosphrous nutrition on the yield of Rafal winter oilseed rape (Table 7.12). The phosphate

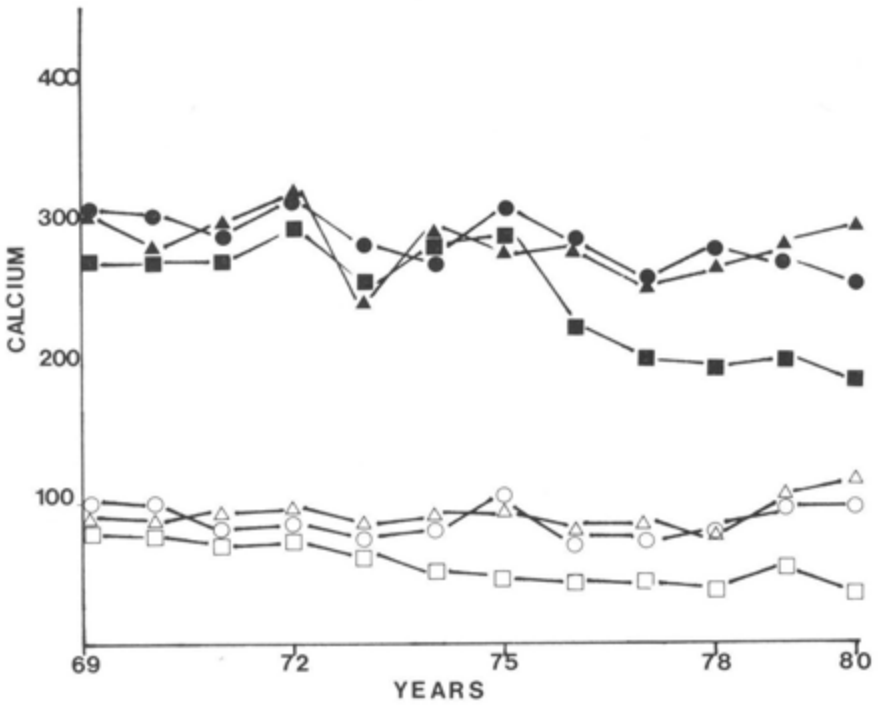


Figure 7.10 The effect of the form of nitrogen and liming on soil calcium mg 100 g^{-1} under grass plots. Closed symbols limed, open unlimed ● ○ nitrochalk, ▲ △ urea, ■ □ ammonium sulphate

TABLE 7.11 The effect of soil acidity and phosphate fertiliser application on yield of spring barley (Mg (tonnes) ha^{-1})

P added	soil pH				
kg ha^{-1}	4.8	5.1	5.4	5.8	6.3
20	1.33	2.96	5.27	5.98	6.17
60	2.30	4.40	5.81	6.05	6.01

TABLE 7.12 The effect of soil acidity and the addition of a phosphate fertiliser and the yield of oilseed rape (Mg (tonnes) ha^{-1})

P added	soil pH				
kg ha^{-1}	4.8	5.1	5.5	5.8	6.2
0	2.2	3.0	3.6	3.8	4.4
40	3.7	4.1	4.5	4.5	4.6

fertiliser reduced the effect of soil acidity on oilseed rape. Yield was maintained at pH 5.5 compared to a decreasing yield below 6.2 when no phosphate was applied. 7037, 7041

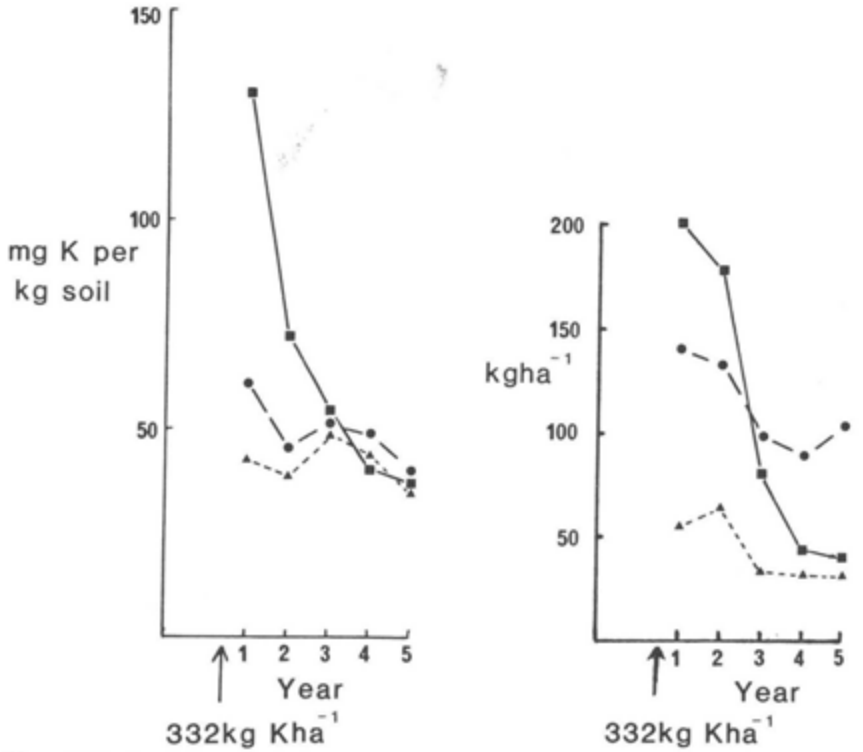


Figure 7.11 The effect of a single potassium application of 332 kg or an annual application of 66 kg ha^{-1} for five years or no potassium on a) the potassium content of soils under grass, b) the annual removal of potassium in two cuts per year. ■ 332 kg K, ● 66 kg annually ▲ control

Potassium

The effects of a single large application of potassium, lower annual applications and no potassium have been assessed on an established grass crop. The single addition (332 kg K ha^{-1}) was five times the annual dressing (66 kg K ha^{-1}) which was added for 5 years. Soil potassium levels fell dramatically in the single application treatment so that after two years it was at a similar level to the other treatments (Figure 7.11a). The similarity of the other 2 treatments suggest that the annual removal of potassium in the crop is greater than the annual application of 66 kg ha^{-1}.

Potassium removal in the harvested crop showed a similar trend to soil K (Figure 7.11b), large initial offtakes were followed by a sharp decline. This luxury uptake during the first two years could lead to magnesium imbalances in the grazing animal (hypomagnesaemia). Annual applications maintained a reasonable level of offtake, approximately 60-80 kg of K more than the control treatment.

Crop yield increased initially and then dropped after two years to give a similar yield to the plots which had received no potassium for five years (Figure 7.12). The total yields of oven dry grass for the 5 years were 40.6,

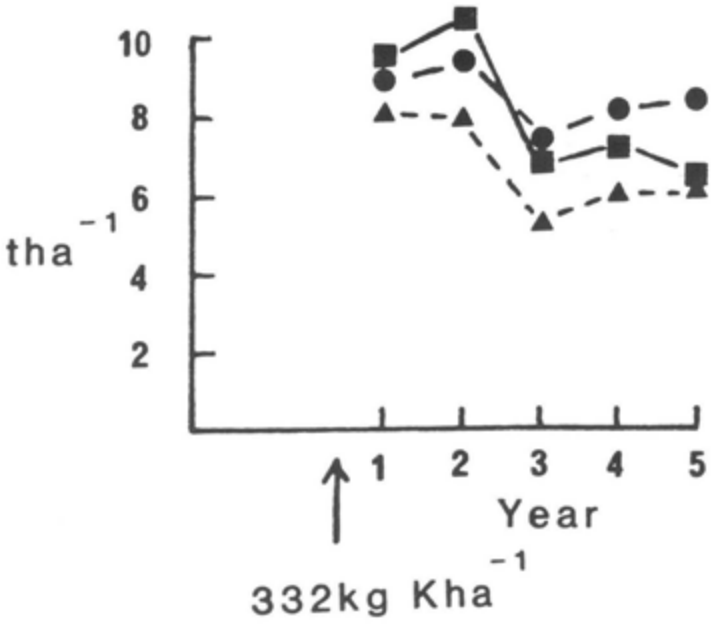


Figure 7.12 The effect of the treatments described in Fig. 7.11 on the annual yield of grass. Symbols as for Fig. 7.11

42.3 and 33.3 Mg (tonnes) ha^{-1} for the single, annual and control treatments. 7041,7037

Selenium

Selenium is essential for good animal growth, but is often found in deficient levels in forage. Immobilization of added selenium compounds and leaching in soil make this a difficult element to supply via the soil. Sodium selenate which is usually rapidly lost from the soil, has been immobilized on pumice granules in an attempt to give a slower release of Se. The behaviour of this material is being assessed.

Residual Effects of Selenium Additions. The trial begun in 1984, on a Countesswells Association Soil has been continued to assess long term residual effects. The mean selenium content in herbage from the untreated plots in 1984 was 0.053 μg g^{-1} (Table 7.13). This is below the minimum needed for healthy animal growth. Plots receiving 10 g Se ha^{-1} (about the recommended level) showed mean values in the first herbage cut of 0.71 μg g^{-1}. This fell to 0.11 μg g^{-1} in the third cut then subsequently increased when grass growth slowed. All these levels are above the minimum required. Concentrations in the first cut resulting from the 30 g Se ha^{-1} application were potentially toxic. Thereafter they decreased to an acceptable level. In 1985 the nitrogen applications, but not the Se treatments were repeated.

TABLE 7.13 The effect of selenium treatment on the Se content of grass ($\mu g\ g^{-1}$ DM) Se0 — No selenium, Se1 — 10 g ha^{-1} Se, Se3 — 30 g ha^{-1}N — 100 kg ha^{-1} N as nitrochalk at beginning of trial and after each cut

	Se concentration						
	1984				1985		
Treatment	1st cut	2nd cut	3rd cut	4th cut	1st cut	2nd cut	3rd cut
Se O	0.057	0.023	0.060	0.094	0.056	0.036	0.060
N Se O	0.032	0.017	0.057	0.082	0.105	0.031	0.043
Se 1	0.69	0.35	0.14	0.26	0.047	0.034	0.031
N Se 1	0.73	0.25	0.08	0.21	0.048	0.028	0.030
Se 3	1.9	0.57	0.34	0.45	0.070	0.041	0.040
N Se 3	2.6	0.60	0.23	0.36	0.070	0.027	0.036

TABLE 7.14 The effect of chelated and non-chelated copper on the yield of winter barley

Soil level[I] mg Cu kg^{-1}	Control yield Mg (tonnes) ha^{-1}	Relative yield (% of control) Copper oxychloride	Copper EDTA	CV%
0.5	8.1	114*	108	8.8
1.1	4.3	115	113	17.9
1.4	8.5	103	104	4.4
1.6	5.9	101	105	7.0
3.6	7.7	102	100	4.0

[I] Extractable soil copper (see Advisory Soil Analysis and Interpretation, Macaulay Institute for Soil Research and Scottish Agricultural Colleges, Bulletin 1, 13 pp)

There was no residual effect of either of the Se applications on Se concentrations in the herbage. 7045, 7079

Effects of Soil Type on Selenium in Herbage. The three trials, utilizing different soil types, which were begun in 1985 (Report No. 55, p.141) have continued. The two nitrogen treatments 0 and 100 kg N ha^{-1} as nitrochalk, were repeated. In 1986 the plots were split with one half receiving Se application at the same rate as 1985 and the other receiving no additional Se. This should allow the possible accumulation of Se to be assessed. Four cuts of herbage were again taken. At the third cut, an effect on sward composition due to the nitrogen treatments was obvious. Se appears to be selectively absorbed by grasses relative to clover and so all harvests from the third cut are being partitioned into grass and clover components and separately analysed for Se. 7079

Micronutrients

It has been suggested that when micronutrients are applied in a chelated form smaller quantities are needed because uptake is more efficient. Five trials have compared the response of winter barley to copper sprayed as both the non-chelated oxychloride and the chelated EDTA (ethylenediaminetetraacetic acid). Each product supplied 0.25 kg ha^{-1} of copper as a split dressing between March and May. A non-ionic wetting agent was used. Data are given in Table 7.14. Only copper oxychloride at the site with the

lowest quantity of available soil copper gave a significant response(*). There was no clear difference in the efficiency of chelated and non-chelated forms. Copper oxychloride is cheaper. At present a copper application to cereals is recommended where soil copper is 1.6 mg kg^{-1} or lower. There appears to be no justification for changing this critical level, even where the expected yield is high as higher yielding crops do not seem to be more prone to copper deficiency.

Work in collaboration with the Department of Soil Organic Chemistry on the mobilisation of the micronutrients Cu, Zn, Mn and Co into the soil solution of the rooting zone of plants has continued[12]. In 1986 the investigation was extended to include winter wheat and oilseed rape. Mobilisation of micronutrients occurred into the rooting zones of these crops with the maximum effect corresponding to the period of maximum growth in early spring (see also page 106). This is similar to the situation reported for winter barley (Report No. 55, p 142) and contrasts with the much later period of mobilisation previously observed for spring barley.

7041, 4803

Soil Physical Properties

Impact on Potato

Effect on Nitrogen Supply. Nitrogen uptake by the potato crop depends on root growth and distribution. Where soil physical conditions limit root growth, a smaller volume of soil is exploited by the crop and so less nitrogen is available to the plant. The importance of soil physical conditions was shown in an experiment where potatoes were grown on two contrasting soil types, with the same rate of nitrogen application (200 kg ha^{-1}), within a single field. On the Foudland soil (a freely drained loam topsoil with a fine sandy loam subsoil) root system development was more rapid and extensive than on the Ordley soil (an imperfectly drained fine sandy loam topsoil with a sandy clay loam subsoil). In 1985, a wet year, the coarser texture of the Foudland soil allowed easier root penetration (Figure 7.13) and drainage than in the finer textured Ordley soil, resulting in greater nitrogen uptake by the crop (Table 7.15). The higher nitrogen uptake resulted in more rapid and extensive canopy development on the Foudland soil, increased the amount of light intercepted and ultimately gave a higher yield of potatoes. Root distribution and nutrient inflow rates for the two soil types are currently being calculated. 7044, 7047, 7076

Effect of Irrigation. In collaboration with SCRI, root growth and distribution in relation to water supply has been investigated for a second year. In 1986 a portable rain shelter was used to ensure drought conditions on half the plots, while the other plots were irrigated. Samples of roots and plant dry matter are currently being analysed for nutrient uptake and inflow rates. On some of the plots a traffic pan (with a strength of 2 MPa) was found which roots were unable to penetrate on the droughted site (Figure 7.14).

Figure 7.13 Foudland soil (a) and Ordley soil (b) showing canopy and root development on the two soil types just after tuber initiation

TABLE 7.15 The effect of soil type on nitrogen uptake and yield

Soil type	Nitrogen uptake (kg ha^{-1})	Tuber yield (Mg ha^{-1})
Foudland	154	42.6
Ordley	122	38.6

Figure 7.14 Effect of a traffic pan on root distribution of the potato under drought conditions

Soil Condition and Powdery Scab. The effect of a tine cultivator, a shakaerator and a paraplough on growth, nutrient uptake and the incidence of powdery scab *Spongospora subterranea* infection have been assessed[13]. Both the paraplough and the shakaerator improved the physical properties of the soil, allowed deeper root growth than in the soil treated with the tine cultivator. Total nitrogen uptake by the crop was higher on the paraplough and shakaerator treated soils. Tubers from the shakaerator treated soil had a significantly higher ($P<0.05$) incidence of powdery scab. The subsoil of the shakaerator treatment had a higher water content ($P<0.05$) at a high water potential (-1 kPa) than with the paraplough treated soil. In the year of the trial (1985) this would have resulted in a higher mean water potential and a longer period when the soil was at a high water potential with the shakaerator treatment. The mechanisms of the effects are not wholly clear because although the water content at high potentials was similar for tine cultivated and shakaerator treated soil, tubers from the tine cultivated treatment had significantly less powdery scab. The shakaerator treatment

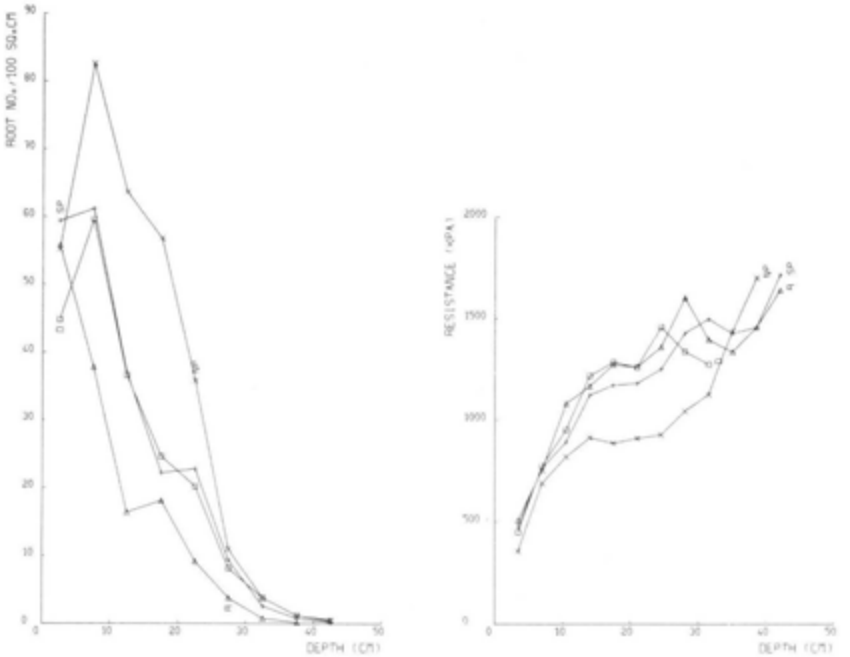


Figure 7.15 Root growth (a) and soil penetration resistance (b) under four cultivation techniques. NP — normal ploughing, SP — shallow ploughing, D — Discing R — rotaspiking

may have provided the optimum duration of saturation and flushing conditions which favour rapid disease development. 7044

Impact on Barley

Effect of Cultivation. The effects of cultivation on the growth of winter barley have been studied in conjunction with NOSCA at the Tillycorthie farm. As with the 1983/84 and 1984/85 seasons, in 1985/86 there was no significant difference in the final yield of winter barley grown with normal ploughing, shallow ploughing, discing and rotaspiking. Root growth and distribution however differed under the range of cultivation treatments. Root growth was related to soil penetration resistance (Figure 7.15). Root distribution was assessed using both the profile-wall and root-coring techniques. 7044

Effects of Compaction. Two varieties of spring barley, Corgie and Golden Promise were grown on a Laurencekirk Association soil with two levels of compaction. At the 4 leaf stage, Golden Promise had taken up more phosphate than Corgie which was taller and had absorbed more calcium and magnesium. At maturity, Corgie had a greater dry weight of straw and a higher potassium and magnesium content. Compaction

increased the uptake of potassium and magnesium by both varieties. Depriving the plants of water for 1 week at tillering stage led to reduced potassium, phosphate and magnesium uptake in both varieties. The influence of root growth, in the early stages of development, on uptake is being assessed. 7044, 7076

The Effects of Freezing

A freeze/thaw cycle has been shown to increase substantially the losses of gaseous nitrogen from an upland soil fertilised with urea[14]. This study was undertaken as part of a study of seasonal changes of nitrate in upland streams[7,15]. The conclusions are, however, significant in relation to the recent trend of applying urea fertiliser early in the year. The importance of these freeze/thaw cycles also has wider implications for soil and water chemistry[15]. Within soil cores, under laboratory conditions, the leaching of elements such as aluminium, potassium and carbon were increased by a freeze-thaw cycle. 7037, 7039

Root Growth and Activity

Root systems are the means by which plants interact with the soil to obtain their supply of water and mineral nutrients. The amount of root in the soil determines the necessary rates of processes such as nutrient inflow and the significance of a number of soil properties some of which are affected by the activities of the roots.

Root Distribution

The volume of soil available to the plant is determined by its distribution with depth, its lateral spread and the distribution of root length within these limits. Several studies have aimed to increase understanding of distribution.

Distribution in Potato. Using data from several experiments carried out over a number of years, attempts are being made to model the root distribution of the potato crop. Information suggests that the root system is found mainly under the ridge with only a few (<5%) of the roots under the furrow. Within the ridge there was also a distribution away from the stem (centre of row). Figure 7.16 shows the difference in the distribution of primary roots (diameter >0.20 mm) in the centre of the ridge (12.5 cm either side of the stem) and at the edge of the ridge (between 12.5 and 25 cm either side of the stem) just after tuber initiation. 7076

Variation in Root Distribution in Spring Barley. In association with the Scottish Crop Research Institute twenty-five varieties of spring barley have been grown in either glass observation tubes or observation boxes as a means of characterizing the extent and type of variation in root system development which occurs. It is also hoped, by comparing the times taken

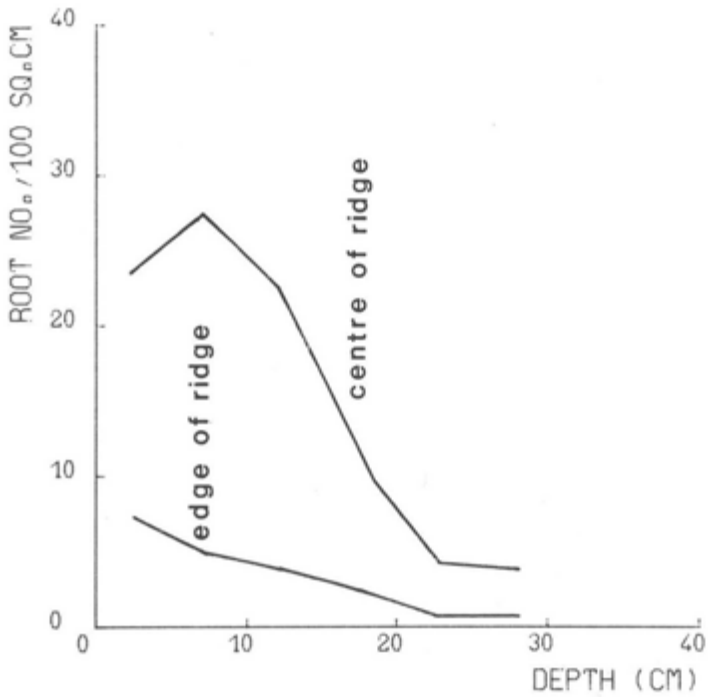
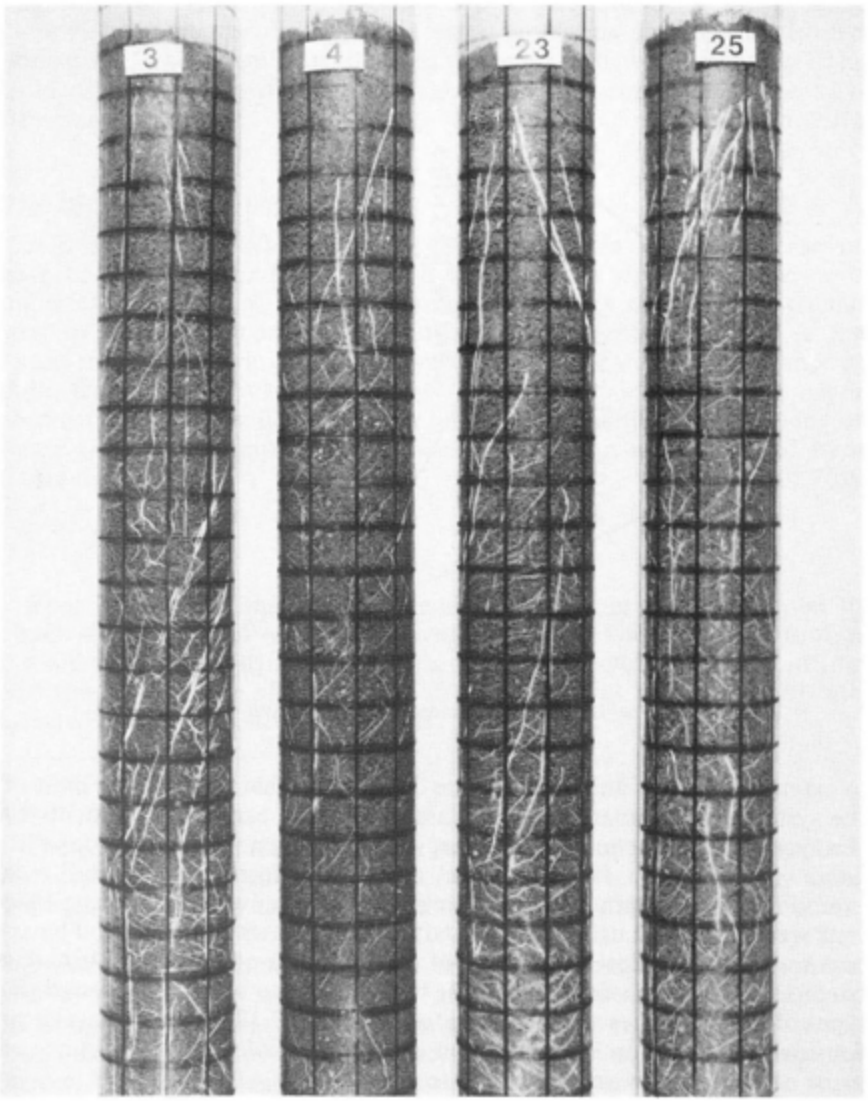


Figure 7.16 The distribution of potato roots with depth within the ridge

to extend to shallow and intermediate depths with that to reach the limit of the system (approximately 1m), to assess whether early measurements of this type, would have predictive value, in identifying potential varieties with good root extension from breeders' advanced selections. The ability to extend rapidly to depth is seen as being of selective advantage. During 1986 tests were conducted using both a sandy Boyndie series soil and a soil based compost so as to allow assessment of the influence of a range of growing conditions. Although data from these trials has yet to be fully processed the types of variation present are illustrated by Figure 7.17. Barley plants show considerable variation in distribution and the physiological significance of some of these differences will be assessed.

A recent paper[16] has modelled the implications, for growth rate, nitrogen supply and nitrogen inflow rates, of carbon partitioning within the root system leading to variation in specific root length (cm g^{-1}). A large specific root length represents effective carbon use and may lead to high relative growth. Similarly the development of a good cover of root hairs has been suggested as being of selective advantage. Many of these characteristics vary in the barley varieties under investigation (Figure 7.18). The similarities in rates of growth allow them to be used as a model system to test the importance of factors such as root diameter (specific root length), root hair density and root length density. 7077



Variation in the root system distribution of 4 spring barley varieties grown in glass observation tubes. Varieties differ in overall root density which was highest in variety 3 Plumage and lowest in 4 Keria. Distribution is stratified and relatively deep in 23 Heriot and relatively even in 25 Ayr where there is a preponderance of fine roots. Squares are of 2 cm side.

Root Development and Nutrient Inflow

Field Measurements on Potato. Conventional methods of measuring the rate at which roots absorb nutrients in the field are problematical. Most problems are related to the limited accuracy with which the size and activity of the root system can be measured *in situ*[19]. Many of these problems can be

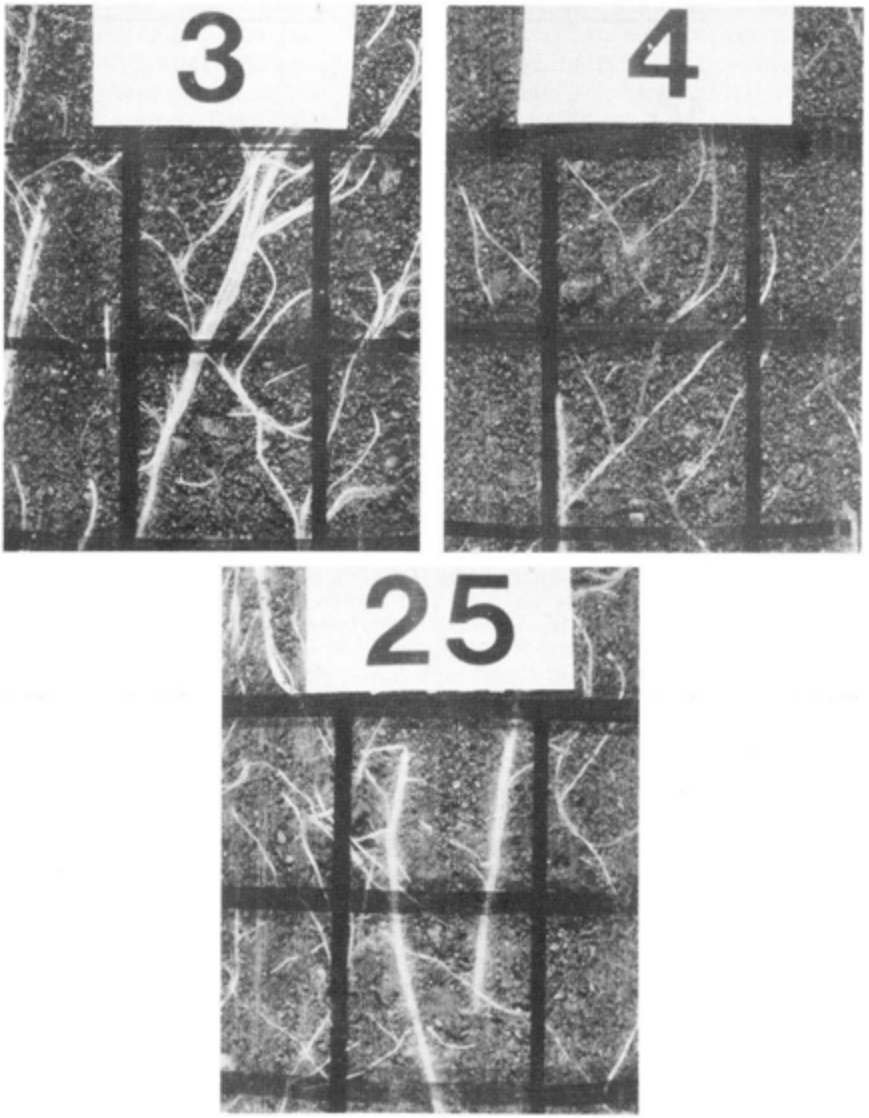


Figure 7.18 Variation in the root morphology of spring barley a) Keria has high specific root length, limited branching and low density, b) Ayr has a lower specific root length, more branching and prolific root hair development, c) Plumage has a high root length density

overcome by isolating the roots of potato plants growing in the field and supplying isotopically labelled nutrients (see also p 151). The method was used with plants which received no fertilizer nitrogen (low N) or 200 kg N ha^{-1} as calcium nitrate (high N); the rate of nitrogen inflow has been related to root length. As the length of root exposed to the solution decreased, the rate of nitrogen inflow increased (Figure 7.19). This confirms

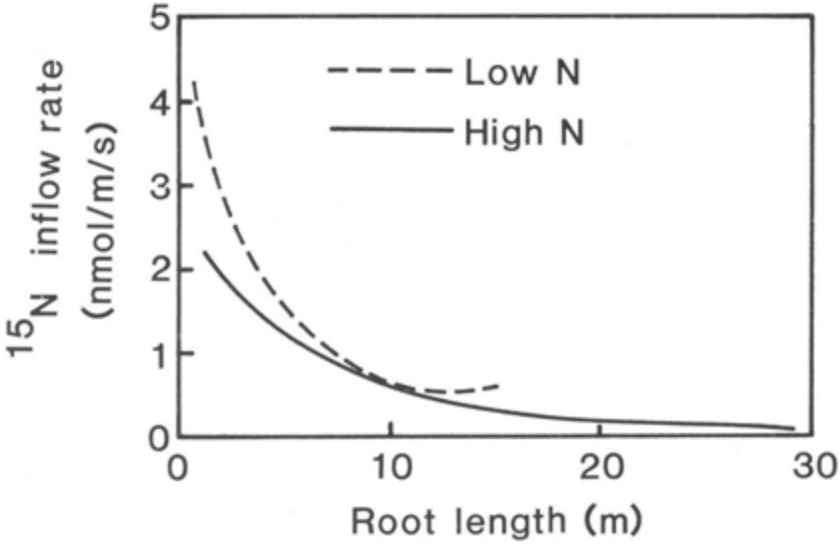


Figure 7.19 Relationship between the length (L) of root exposed to ^{15}N solution and the ^{15}N inflow rate (I) in potato receiving either Low N: no fertilizer applied or High N: 200 kg N ha^{-1}. Regression equations for the curves shown:

Low N: $\frac{I}{L} = \exp(4.06 - 0.41L + 0.02L^2)$, for $0.9 > \frac{}{L} < 15.4$

High N: $\frac{I}{L} = \exp(3.37 - 0.21L + 0.004L^3)$, for $1.8 > \frac{}{L} < 29.6$

n = 46 in both cases

results found previously in laboratory experiments and suggests that as the fraction of the root system with access to a readily-available source of nitrogen decreases, the inflow rate to that part of the system increases in a compensatory manner. Nitrogen deficient plants (low N) seem to have greater capacity for such compensation than do plants whose roots are growing in soil well supplied with nitrogen (high N). This technique has great potential for the investigation of other physiological aspects of root performance under field conditions. 7039, 7047

Measurements on Trees. The critical importance of root length to the nutrient inflow rates, especially for phosphorus, needed by trees, has been reviewed[17] as has the potential for modifying this using plant growth regulators[18]. Current studies are investigating the effect of soil acidity on root development in *Prunus avium* and its consequences for nutrient inflow of major nutrients. 7076, 7077

The Soil-Root Interface

In conjunction with the department of Mineral Soils a study of the characteristics of the root-soil interface and its effects on root functioning,

especially the supply and absorption of water and mineral nutrients has been initiated (see also pages 41 – 44). Studies to date have concentrated on documenting the physical adherence of the soil material to the root surface and the changes which occur in roots as they age. The roots of barley grown in either a sandy Boyndie series soil or a soil-based compost always have a cylinder of soil firmly attached to the root surface (Figure 7.20a). The extent of this soil cylinder and its resistance to removal by water increases with age. The surface of soil grown roots is rarely visible being coated with fine soil material firmly attached by a film with a mucilaginous consistency (Figure 7.20 b,c). This material can fix sand grains to the root surface and to each other (Figure 7.20 c,d). With time this film disintegrates to give material of a more granular nature (Figure 7.20 e). This change seems to be an effect of age rather than altered soil condition. Where young and old roots are present in the same area of soil the film of mucilage is present around the young roots and the granular material around the old. The surfaces of both roots and root hairs are covered by amounts of tightly adhering clay and fine silt particles (Figure 7.20 f). Particle size analysis carried out by the Department of Mineral Soils has shown that the Boyndie series soil from the rhizosphere had a higher clay and fine silt content than was found in the bulk (non-rhizosphere) soil. Studies of roots, of a range of ages, has shown that the association between roots and soil is always intimate (Figure 7.21 a,b) so that it is important to interpret data on the uptake of mineral nutrients in the context not of a root in contact with soil solution but of a root largely covered by firmly adhering mineral materials. As the clay content of soils has a major effect on their water and nutrient holding properties the increased amount of clay found around roots may have a major modifying effect on supply to the root surface. The mucilaginous covering, which will under normal conditions, be wetted and dried, may well influence the ease with which water moves to the root and so account for part of the resistance to movement which seems to exist at the root soil interface. The use of the cold stage of the SEM is proving invaluable in studies of root structure (Figure 7.22 a,b) and the effects on the root of infection with vesicular arbuscular mycorrhizas. 7078

Development and Advisory Work

Soil Fertility Information System

Data from the East and West Colleges of Agriculture have now been integrated into the Soil Fertility Information System (SFIS) for Scotland. A Working Party from the Institute and Scottish Agricultural Colleges has prepared its first report based on data collected during 1985 as part of routine soil analysis. The samples used were restricted to those taken for routine analysis. Samples taken in response to a crop or stock problem were excluded.

Data on soil pH and both macro- and micronutrients have been summarised for 13 different farming systems, subdivided on the basis of the number of years of grass in the rotation and the rate of fertiliser nitrogen. Table 7.16 shows data from about 6000 fields in the North of Scotland; here

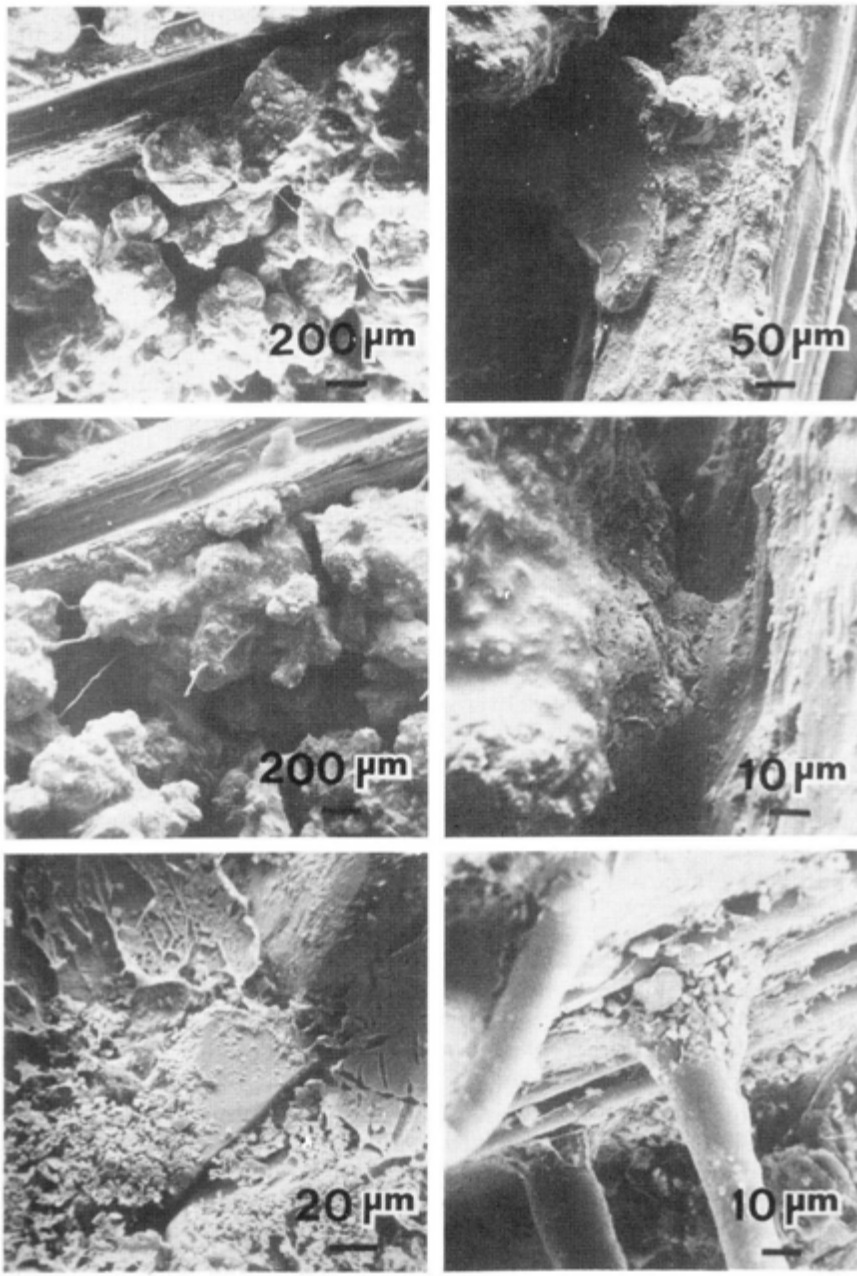


Figure 7.20 The root surface of barley seen on the cold stage of a scanning electron microscope, a) root with adhering sand/microaggregates, b) surface covering of the root with fine material, seen after the root was partially longitudinally sectioned, c) adhesion of particles to root surface with muscilagenous material, d) detail of adhesion of sand particle (left) to root surface (right), e) change in muscilage with age from film to granular consistency, f) root hair at root surface with adhering silt and clay particles

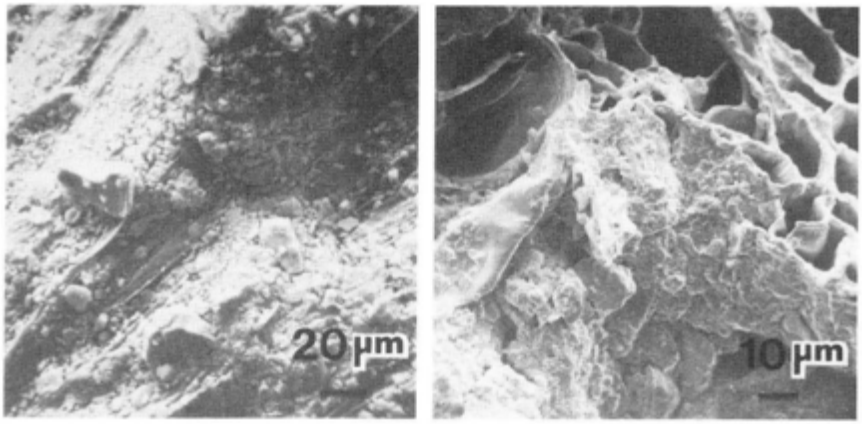


Figure 7.21 The root surface of barley seen with the SEM a) older root entirely covered by a layer of tightly adhering silt and clay, b) intimate adhesion of soil materials to root seen here in section

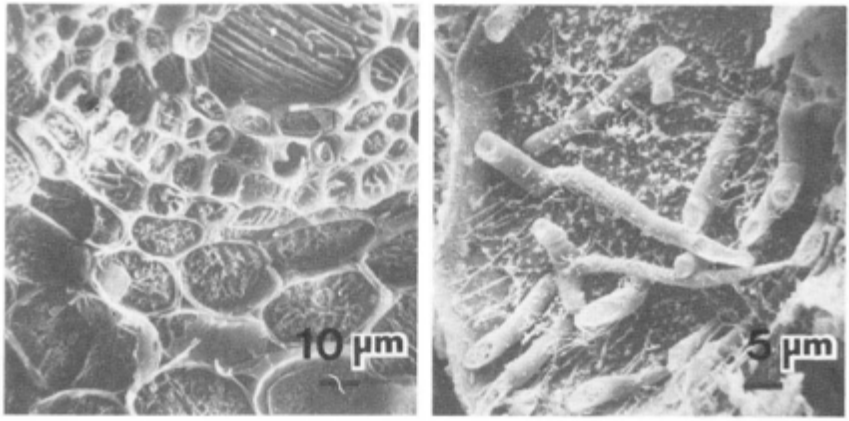


Figure 7.22 a) freeze-fractured barley root seen in TS under the SEM. Outer cortical cells, endodermic and stele are clearly visible, b) fractured section of an outer cortical cell showing fungal infection believed to be the arbuscular component of a vesicular-arbuscular mycorrhizal association

the number of farming systems have been reduced to 7. The greatest proportion of fields with soil pH >6 are in arable rotations without grass. Although the highest rates of fertiliser nitrogen are probably applied on these farms, the acidifying effect of nitrogen fertiliser appears to have been more than compensated for by the use of lime. The same trend of the association of higher soil pH with higher fertiliser inputs is shown comparing column 3 and 4, and 5 and 6.

Information on soil phosphorus suggests that the amount of phosphate fertiliser could be reduced on one-third of the fields under continuous

TABLE 7.16 Soil pH — number of fields as per cent of those analysed

	Number of years in 5 in grass						Hill Sites
	1	1-2	2-4		4-5		
	Nitrogen used kg ha^{-1}						
	any	any	<125	>125	<125	>125	
Soil pH range							
<5.0	1	1	8	2	14	2	41
5.0-5.4	6	7	21	9	30	9	27
5.5-5.9	35	46	40	49	33	54	17
6.0-6.5	55	45	24	38	18	27	11
6.6-7.0	3	1	1	1	2	6	1
>7.0	0	0	6	1	3	1	3

TABLE 7.17 Soil phosphorus — number of fields as per cent of those analysed

	Number of years in 5 in grass						Hill Sites
	1	1-2	2-4		4-5		
	Nitrogen used kg ha^{-1}						
	any	any	<125	>125	<125	>125	
P status							
very low	1	1	5	3	10	4	24
low	7	16	30	21	37	38	41
moderate	56	63	51	56	41	50	22
high	36	21	14	20	12	9	13

TABLE 7.18 Soil potassium — number of fields as per cent of those analysed

	Soil Series					
	Foudland	Tarves	Boyndie	Countess-wells	Corby	Pitmedden
K status						
very low	0	0	3	2	2	2
low	14	15	33	28	25	23
moderate	71	69	62	61	66	64
high	14	16	2	9	6	11

arable cropping. Here the aim is to maintain a moderate soil P status by annual addition of phosphate fertiliser at a rate linked to crop responsiveness (Table 7.17).

The fertility status of different soil series can also be assessed. Table 7.18 shows the potassium status of six soil series based on between 200 and 400 soils per series. The freely draining Boyndie series soils derived from fluvioglacial sands appear less well supplied with potassium than the other soil types. However, the proportion of soils in each status category are rather similar for a number of series. Potassium fertilisers and manures, and crop and animal management, have probably exerted a greater influence on K status than has soil series. As the amount of data is increased

TABLE 7.19 The correlations between available soil phosphorus measured using an anion-cation resin, with other methods for comparison, and response to applied phosphate fertilizers

	Soil Series				
Method	Tarves	Foudland	Insch	ORS	Countess-wells
Mixed resin	0.765***	0.461*	0.657***	0.642***	0.698***
Cl resin	0.626***	0.495*	0.632***	0.521**	0.783***
Acetic acid	0.656***	0.360NS	0.594**	0.614**	0.644**
Bicarbonate	0.524**	0.584**	0.561**	0.402*	0.726***

*, **, *** correlations significant at P⩾0.005, 0.01 and 0.001 respectively

in the Soil Fertility Information System the interaction between farming system and soil type should become clearer.

Fewer soils are analysed per year for micronutrient status resulting in a slower accumulation of data in the system. However, micronutrient data from earlier years has been processed manually and combined with computerised data. This work has been reported in collaboration with the Department of Soil Survey for Caithness[20]. 7041

Advisory Analyses. In 1986, 7393 advisory samples were processed for NOSCA. Sulphur was determined in 1650 of these samples and over 1100 samples required the determination of combinations of boron, manganese, copper, cobalt and molybdenum. Forest soil samples from throughout the UK, sewage sludge samples from Grampian Regional Council and herbage samples associated with poor crop growth or animal problems were also analysed. A paper on the effect of the wet 1985 conditions has been published[21]. 7043

Advisory Methods

Micronutrients. At present a separate soil extract is used for Co and Mo so greatly increasing the overall analytical task. A method for determining these two elements in a combined extract has been developed which is as effective, for practical purposes, as the present method in placing soils into status categories[22]. 7041

Phosphate. Studies of the possibility of using a mixed anion-cation exchange resin in advisory soil analyses are continuing. Values for available phosphorus obtained using a single anion resin (Cl form) and a mixed anion-cation (Cl-NH_4 form) resin differ substantially (Table 7.19). Although the two resin types are not equally good at predicting fertiliser response, the mixed resin is only rarely poorer than the chloride resin and on some soils it is superior. The mixed resin was always superior to acetic acid, the current standard method and, more often than not, better than bicarbonate. Acetic acid (0.43M) and mixed resin extractable phosphorus have been compared using soils (air-dried) from a long term experiment where large, once only, applications of phosphorus, as triple

TABLE 7.20 The mean annual grass yields (2 cuts) obtained over a period of 11 years (Mg (tonnes) ha^{-1} DM) with phosphate and lime treatments

	Superphosphate	Rock phosphate
lime	8.79	8.44
no lime	8.49	8.48

superphosphate or ground rock phosphorus (at a rate of 2445 kg P ha) and/or lime were given in 1968.

There was good correlation between acetic acid and mixed resin-extracted P for the limed and unlimed plots with and without triple superphosphate although the resin tends to extract consistently more P than acetic acid. Where rock phosphate had been used the relationship between the two extractants was poor, with acetic acid overestimating plant-available P. Both methods tended to overestimate on the limed soils. These apparent differences in availability between phosphate forms were not reflected in the yields obtained (Table 7.20). 7037

Radioisotope Services

Radioisotope Services

Radioisotope Use. Radionuclides continue to be used extensively throughout the Institute.

In the Department of Plant Physiology both ^{36}Cl and ^{45}Ca were used to determine the fluxes of these elements through Sitka Spruce needles so that a measure of their contribution to throughfall could be obtained. ^{58}Co and ^{60}Co were used in single and dual isotope experiments for studies on cobalt uptake and transport in wheat seedlings. The short lived isotopes ^{43}K and ^{64}Cu (half lives of 12.4 and 12.8 hours respectively) obtained by irradiation in the Scottish Universities Reactor at East Kilbride were used to follow the uptake and efflux of potassium in Sitka Spruce needles and as a tracer in plant uptake and translocation experiments respectively. Studies on the mineralisation of sulphur in plant residues using ^{35}S were continued by the Department of Soil Microbiology as were the transformation of ^{14}C labelled fulvic and humic acids and soil carbohydrates in the Department of Soil Organic Chemistry. ^{14}C labelled plant matter was prepared using ^{14}C glucose. The Rowett Research Institute and the Department of Mineral Soils utilised ^{137}Cs in studies of the adsorption of radio-caesium by clay minerals. Samples of ^{13}C and ^{14}C labelled potato plants have been processed for the Scottish Crop Research Institute. ^{35}S was also used in an evaluation of the efficacy of micronised elemental sulphur applied as thiovit for the correction of sulphur deficiency. Rye grass was grown in a media containing ^{75}Se to provide a source of labelled plant matter. 7049

Radiological Safety. Following the introduction of the Ionising Radiations Regulations Act of 1985 several changes were made to working practices with radionuclides within the Institute. A new comprehensive Code of Practice was issued and new monitoring schemes and a staff

TABLE 7.21 Contamination monitoring 1 — 8 May. The results are in arbitrary units of radioactivity

Date	Dew	Rain	Milk	Grass
May 1	0	0	0	0
2	3	1	0	0
3	230	80	0	30
4	1264	343	16	53
5	170	73	27	18
6	46	53	14	9
7	117	69	16	158
8	48	34	0	25

TABLE 7.22 Regional radiation check of pasture herbage. All results in CPM above background

Site	7/5	8/5	9/5	10/5	11/5	12/5	13/5	14/5
Benbecula	292	232	173			147		
Dingwall	225	217	155	138			99	115
Elgin	165	173	133				34	
Inverness	138	129					78	68
Keith-Hunt	86	50	49		41		49	34
Keith-Roth	49	60	53		53		24	21
Kirkwall	319							
Lerwick	154	142	125	94		79		63
Portree	86	153	55	150		77	53	47
Stonehaven	111	72	95	25				32
Stornoway	125	100	142	119	92	155	96	100
Thurso	222	201	195	102	148	91	104	107
Turriff	76	66	83	36	25	13		24

Site	16/5	19/5	21/5	28/5	June	July	Aug	Sept
Benbecula	122	59		59	32	18	10	
Dingwall		54	55	21	16	10	9	9
Elgin	27		32		11	8	6	
Inverness		37	33	22	14	11		
Keith-Hunt	21	18	18	25	11	13	6	
Keith-Roth	27			12	11	8	6	
Kirkwall	68	38	24	14	14	12	9	4
Lerwick	51		43	16	24	14	8	
Portree	32	50	20	21	11	18	15	
Stonehaven	29	15	15	11	5	5	2	
Stornoway	75		51	21	28	15	14	
Thurso	79	59	38	11	12	40	13	10
Turriff	45		31		6	5		

training programme initiated. The Institute's Radiation Protection Advisor is now also responsible for the RRI and similar procedures have been initiated there. A new schedule of authorisation for the keeping of radioactive isotopes has been received from the Radiochemical Inspectorate of the Scottish Development Department under Section 1 of the Radioactive Substances Act of 1960. 7050

The Chernobyl Incident

The Chernobyl accident occurred on the morning of Saturday 27 April, 1986. Monitoring began here on Wednesday 30 with dew, rain, milk and grass samples being assessed (Table 7.21). In the following week the Scottish Development Department asked for the coordination of the collection and monitoring of samples of pasture herbage from an area ranging from Shetland to Stonehaven to Benbecula. Weather records show that the radioactive cloud was driven north west over Scotland on 3 May, turned west over the Atlantic Ocean and having described an anti-clockwise loop returned here travelling north eastwards on 7 May. The results of contamination monitoring closely resemble the weather pattern (Table 7.22).

An information 'hot line' was operated during May. Samples sent in by the general public for analysis included duck's eggs, goat's milk, spinach and lettuce. The regional survey of pasture herbage is on-going (Table 7.22). The assistance of the staff of NOSCA in sending samples was invaluable. Tests continue on samples and include cereals, prior to malting, from The Distillers Company, water samples from the Grampian Regional Council and various commercial firms. 7049

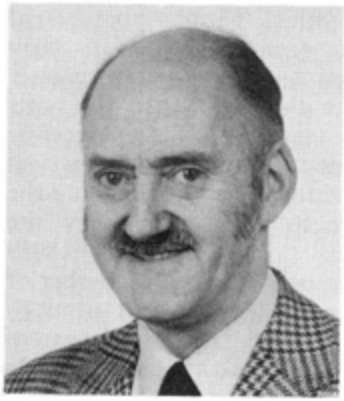
References

1. The influence of nitrogen supply on potato yield and quality. By P. Millard and L.A. Mackie. Technical Note No. 8, 1 pp. Macaulay Institute for Soil Research, 1986.
2. Producing quality fruit – water and nutrient supply. By D. Atkinson, *The Mountaineer Grower*, **463**, 3-15, 1986.
3. Options for orchard floor management. By D. Atkinson. *The Mountaineer Grower*, **467**, 11-23, 1986.
4. Reduced ruminal degradation of ryegrass caused by sulphur limitations. By P. Millard, A.H. Gordon, A.J. Richardson and A. Chesson. Submitted to *Journal of the Science of Food and Agriculture*.
5. Growth, nitrogen uptake and partitioning within the potato (*solanum tuberosum* L.) crop, in relation to nitrogen application. By P. Millard and B. Marshall. *Journal of Agricultural Science*, **107**, 421-429, 1986.
6. The effects of nitrogen application on growth and nitrogen distribution within the potato canopy. By P. Millard and D.K.L. MacKerron. *Annals of Applied Biology*, **109**, 427-437, 1986.
7. Factors influencing nitrogen inputs and outputs in two Scottish upland catchments. By A.C. Edwards, J. Creasey and M.S. Cresser. *Soil Use and Management*, **1**, 83-87, 1985.
8. The accumulation and storage of nitrogen by herbaceous plants. By P. Millard. Submitted to *Physiologia Plantarum*.
9. Short-term uptake rates and partitioning of nitrogen in a potato crop. By D. Robinson and P. Millard. To appear in *Journal of Experimental Botany*.

10. Estimation of percentage ground cover in potatoes by optical radiance measurements. By R.V. Birnie, P. Millard, M.J. Adams and G.G. Wright. *Research and Development in Agriculture*, **4**, 33 – 35, 1987.
11. Soil acidity and its interaction with phosphorus and micronutrients. By A.H. Sinclair and A. Edwards. Technical Note No. 7, 2 pp Macaulay Institute for Soil Research, 1986.
12. Mobilisation of micronutrient cations into soil solution in the rooting zone of barley. By D.J. Linehan, A.H. Sinclair and M.C. Mitchell. To appear in *Journal of Soil Science*.
13. The effect of cultivation on the soil and the incidence of powdery scab *Spongospora subterranea* on potatoes. By L.A. Mackie and J.M. Munro. *Aspects of Applied Biology*, **13**, 293-300, *Crop protection and quality in potatoes*, 1986.
14. The effect of freeze/thaw on gaseous nitrogen loss from upland soils. By A.C. Edwards and K. Killham. *Soil Use and Management*, **2**, 86-91, 1986.
15. Soil freezing effects on upland stream solute chemistry. By A.C. Edwards, J. Creasey and M.S. Cresser. *Water Research*, **20**, 831-834, 1986.
16. Compensatory changes in the partitioning of dry matter in relation to nitrogen uptake and optimal variations in growth. By D. Robinson. *Annals of Botany*, **58**, 841-848, 1986.
17. The nutrient requirements of fruit trees: some current considerations. By D. Atkinson. *Advances in Plant Nutrition*, **2**, 93-128, 1986.
18. The effect of plant growth regulators on the uptake of mineral nutrients and the use of water. By D. Atkinson. *Acta Horticulturae*, **179**, 395-404, 1986.
19. Direct measurements of nitrogen uptake by roots of field-grown plants. By D. Robinson and P. Millard. To appear in *Field Methods in Terrestrial Ecosystem Nutrient Cycling*.
20. The soils of Caithness, Report No. **4**. By W. Towers and A.H. Sinclair. Macaulay Institute for Soil Research, 28 pp. 1985.
21. Mineral washout from the wet — True or False. By A.H. Sinclair, D. Robinson and D.J. Linehan. Norgrass **26**, 10-12, The North of Scotland Grassland Society, 1986.
22. Assessment of soil cobalt and molybdenum status from the simultaneous analysis of acetic acid and ammonium extracts. By J.C. Burridge and A.H. Sinclair. To appear in *Irish Journal of Agricultural Research*.
23. Effects of Chernobyl on the North of Scotland. By H. Shepherd. Milk Topics **36**, 1986.

8. STATISTICS

R.H.E. INKSON



The main work of the Department is concentrated on the provision of a consultancy in the statistical, computing and biomathematical aspects of the Institute's programme of research, and also on ensuring that there are adequate support services in these areas. Emphasis has continued to be given to the value of close collaboration at the planning stages and throughout the conduct of experimental projects, and, of course, this is maintained beyond the statistical analysis to the interpretation and presentation of results stages. Services in computing range from data entry and verification to software, hardware and communications development, and include mapping and database management.

Members of staff have attended meetings and/or conferences of the Biometrics Society, the British Computer Society, the British Society of Soil Science and the Royal Statistical Society. Training courses and exhibitions covering various aspects of computer hardware and software, and communications equipment have been attended. Instruction has been given in the use of computer terminals and the available software and hardware.

The Department has been represented at meetings of the committee which has established, in the Institute's central computer, the Scottish Soil Fertility Information System. During the year computing representatives from the Scottish Agricultural Research Institutes and the Scottish Agricultural Colleges have begun to meet on a regular and informal basis as the Computing Liaison Group with a view to benefitting from the common pool of experience and increasing collaboration.

Computing

The Data General Eclipse C/150 has continued to provide the Institute's central computing service and two additional terminals and two additional printers have been installed. The system has also been upgraded by the addition of a data control unit to relieve the central processor of the task of handling asynchronous communications. This upgrade has had a beneficial effect in preventing further deterioration in response time due to increased user activity. However, a shortage of disk space is now threatening to have an adverse impact on system performance. Thus it has been necessary for computing staff to spend a significant amount of time in backing-off and retrieving users' files to and from magnetic tape. The Perex magnetic tape cartridge reader has been recommissioned for the purpose of transferring to the Eclipse data accumulated in the field by a Microdata data-logger. The

TABLE 8.1 Land Capability for Agriculture in Grampian Region

Class	Missing	2	3	4	5	6	7	Total
Frequency	11	10	125	62	51	53	11	323

pressure for additional terminal connection to the Eclipse has been met by the installation of a port-contending switch which permits up to eight peripheral devices to 'compete' for up to four terminal lines. 8059

The entire communications system has been rewired to permit greater flexibility in connecting peripheral devices to the Eclipse, to the port-contending switch or to the external network via the PAD. Concurrently with this reorganisation, electronic circuitry designed by Technical Services has been inserted in 32 of the 40 communications lines to eliminate the problems of interference generated on these lines when they are unterminated. 8059

The connection to the JANET network has been used by a number of researchers to communicate with collaborating workers and to transmit to the AFRC Computing Centre a Mossbauer spectrum simulation program too large to be accommodated on the Eclipse. One of the PAD lines has been reconfigured so that it is now possible to print out locally files held elsewhere on the network and a print queue has been set up at AFRCCC to facilitate this. Arising from the need to maintain system performance, a number of modifications have been made in 'housekeeping' procedures, some of which have involved the writing of additional system software. 8059

A new version of the copy/extract program ROINN has been developed to allow multiple input files and the additional option of selecting the transpose of the data matrix. An extended chi-squared test subroutine has been written to accommodate a larger number of variances in a group and to provide for the elimination of zero values or selected variances. This has been included in some main programs which called the previous version. Several other statistical programs have been reviewed and received minor amendments. 8059.

Soil Database

The main soil database contains a) a systematic inventory of profile descriptions taken at 5km national grid intersection points throughout Scotland with records of chemical, spectrochemical and mineralogical analysis of samples taken at the 10km intersection points, and b) similar information recorded for sites of special interest or illustrative of the wide range of soils found throughout Scotland. There are now 2181 profile descriptions from the inventory (69% of Scotland) and 1145 from selected batches of special interest, including opencast coal sites and the Loch Fleet acid rain project. Data from the mineralogical and spectrochemical analysis of selected samples are also held in the database. A description of the design and structure of the database together with examples of information extracted from it has been accepted for publication[1]. 2066, 8802, 9012

The soil database has outgrown the Data General software available on the Eclipse computer. Consequently a project was undertaken with the help

of Dr S.M. Deen of the Department of Computing Science at the University of Aberdeen to explore the use of their PRECI relational database system. The work included loading the PRECI system with the soil inventory data from the Grampian Region satisfying the relational considerations. The update, query and retrieval functions of PRECI were investigated, with particular interest in the JOIN facility for merging attributes from the soil survey and soil analysis data. The data from the 323 profiles in the Grampian Region were summarised in tables showing frequency distributions for a range of attributes including land capability for agriculture (Table 8.1). 8059, 8802, 9802, 9012, 9013

Soil Fertility

The program written to produce advisory reports on soil nutrient status and lime requirement has been operational for the greater part of the year. Additional programs have been written to summarise the accumulated advisory data from all three college areas and comprehensive tables of results produced. 7041, 8059

Soil Survey

Data extracted from maps and other records were used to supplement the Soils Inventory database so that 14 variables could be prepared on a Scottish grid basis and maps produced for the BBC Domesday Project. Collaboration was also given in providing graphical output of river levels over a period of time. 8059, 8802, 9802, 9012, 9013

Statistical Advisory and Collaborative Work

Mineral Soils

Regression analysis has been used to investigate the relationship between volume and area in a study of the physical dimensions of fundamental particles of clay minerals. For 10 groups of samples the logarithmic model fitted was

$$\text{Ln(Volume)} = a + b\text{Ln(Area)}$$

Tests of equality were made of the slopes (b) and of the intercepts (a) where slopes were equal. 1061, 8057, 8059

Peat and Forest Soils

The EEC-funded project on mixed stands has continued to generate large quantities of data for processing, statistical analysis and plotting. Further glasshouse experiments related to this project have been designed and data from continuing glasshouse experiments, including weights, chemical composition and pH of leachate were analysed. Amendments were made to programs in the WATER series for handling rainfall data to cope with new options required by the researchers. A magnetic tape containing Irish rainfall data and the corresponding data from the Inchnacardoch and

Culloden sites were processed to produce period totals and analyses of variance for kg/ha of several elements were done. In the case of a range of data from the Culloden site, the combined analysis of variance program, COMBEX, was used. Litter weights and corresponding chemical analysis data from both Culloden and Inchnacardoch were processed and the results plotted against time. Some specific programs were written for this purpose and analyses of variance done where appropriate. The usual range of programs with some additions was used to process whole tree sampling chemical data. The weights of elements in the tree parts were calculated, used for log-log regressions on basal area and the regressions plotted. Analyses of variance were done on plot values estimated from the regressions and lines for different groups compared. Combined regressions were derived where appropriate and plotted. Chemical composition data for peat at Inchnacardoch were processed and analyses of variance done as appropriate. 2807, 8057, 8059

A detailed sampling scheme extending to 1991 with randomly selected co-ordinates within each plot was prepared for experiment 24/64 at Culbin, and a further glasshouse experiment was designed. Data processing and analyses of variance were done on nitrogen mineralisation results, on diameter measurements and on chemical composition of foliage samples from continuing experiments on sewage sludge. Some computer programs were modified or extended to allow researchers in this area more opportunity to examine and process their data directly.
2054, 2055, 2056, 8057, 8059

A further experimental site, in Norway, was selected for the Surface Water Acidification Programme (SWAP) and random co-ordinates for the placement of instruments were generated as for the previous sites. The original series of computer programs for processing the data for water and other samples was extended to allow for the increasing range of analytical results arising in this project. 2073, 8057, 8059

Spectrochemistry

In a series of studies of the distribution and background levels of trace element concentrations in Scottish soils, logarithmic transformations of the data were found to be necessary to permit valid tests of significance to be made. The results for chromium and nickel have been published[2].
3007, 8057, 8059

Soil Organic Chemistry

The use of multiple exponential decay curves has continued in studying and interpreting the rates of decomposition of the carbohydrate components of ryegrass and cereal straw during incubation in soil. Two further models were proposed for the process and tested. One has a single exponential-type term with the rate of decay being a function of time, while the other includes a Weibull-type term along with an exponential term. All

three models fitted the data well in most cases. Accounts of the work have been published[3] and submitted for publication[4]. 4020, 8057, 8059

Microbiology

Regular use has been made of the revised program for processing and interpreting dilution series data to estimate the numbers of organisms in soil samples and provide confidence limits for the estimates. Chi-squared tests on contingency tables and analyses of variance were used in a study of the effect of time from sowing on the degree of decomposition of the cortex of roots for four different crops. Logarithmic transformation of numbers of organisms have been used prior to analyses of variance. A range of studies covering microbial biomass, biomass sulphur and carbon, microbial decomposition of tree bark and its use in horticulture, and the mineralisation of organic sulphur have provided large quantities of data for analysis of variance, hypothesis testing and graph plotting.
6025, 6027, 8057, 8059

Soil Fertility

Collaboration has continued in the design of field and glasshouse experiments, and plans produced for a range of experiments on different topics. The regular processing of field and laboratory data, statistical analyses, and the interpretation and reporting of results have been done.
7037, 7038, 7039, 7041, 7042, 7044, 7046, 7047, 7048, 8057, 8058, 8059

In studies of the effects of soil physical properties on crop root distribution, a number of computer programs were written to process and analyse data on soil water content, resistance to a soil penetrometer, tensiometer readings and root counts. The initial processing involved unit conversion, calculation of means and standard errors, plotting results against depth, analysis of variance, where possible, and plotting treatment means. The area under graphs was used as a measure for correlating resistance and root count, for example, regressions were fitted using depth of sand and gravel or water table as independent variables, and a calibration equation for temperature and resistance was derived. 7044, 8057, 8059

The preparation for combined analysis over a number of years of accumulated records from some series of experiments has begun. The program, COMBEX, developed earlier (Annual Report No. 55, 1985), is proving valuable for this purpose. An account[5] of work relating crop responses to phosphorus fertiliser to laboratory measurements of soil phosphorus has been accepted for publication.
7037, 7041, 7048, 8057, 8058, 8059

In experiments on the effect of sulphur on grass quality, amino acids, amides and digestibility measurements were processed and statistical analyses done. The study of the pattern of plant growth has continued, and physical and chemical data obtained throughout the growing season have been processed and analysed. 7047, 7048, 8057, 8059

Soil Survey

For a range of physical soil properties on topsoil, subsoil and parent material, analysis of variance was used to assess the variability of the results over a series of 10 profiles. Models were obtained for percentage moisture in terms of moisture release characteristics, and areas under the curves estimated. Particle size distribution was plotted against moisture content. Among the properties examined or tested in the models were bulk density, organic matter content, liquid and plastic limits, and cation exchange capacity. 9012, 8057, 8059

References

1. Design of a database for Scottish soils. By K.W.M. Brown, J.H. Gauld, B.F.L. Smith, D.C. Bain, J.C. Burridge and R.H.E. Inkson. To appear in J. Soil Science.
2. Total chromium and nickel contents of Scottish soils. By M.L. Berrow and G.A. Reaves. Geoderma, 37, 15-27, 1986.
3. Decomposition of carbohydrates of ryegrass and straw in soil. By M.V. Cheshire, R.H.E. Inkson and C.M. Mundie. Volume II Transactions XIII Congress of the International Society of Soil Science, 563-564, 1986.
4. Studies on the rate of decomposition of plant residues in soil by following the changes in sugar components. By M.V. Cheshire, R.H.E. Inkson, C.M. Mundie and G.P. Sparling. Submitted to J. Soil Science.
5. Estimates of soil phosphorus for different soil series. By J.W.S. Reith, R.H.E. Inkson, N.M. Scott, K.S. Caldwell, J.A.M. Ross and W.E. Simpson. To appear in Fertilizer Research.

9. SOIL SURVEY

J. S. BIBBY

The work of the Department has been carried out, throughout the year, in an atmosphere of uncertainty following the various announcements made by the Department of Agriculture and Fisheries for Scotland (DAFS) over the merger of the Hill Farming Research Organisation, the remit and programme of the new unit and its location. Much more disturbing however has been the substantial reduction in funding of soil research, of which the Department has borne a heavy share. When cuts are fully implemented the Department strength will have been reduced by 50% from its maximum in 1975 and be at its lowest since 1960. In the face of statements from DAFS that the new Macaulay Institute will be a land use institute it is curious that it has inflicted severe damage on a Department clearly identified with land use issues.

Despite these problems the major task of the surveyors, commissioned by the DAFS Land Use Branch in 1984, is approaching completion ahead of schedule. Over 1790 km^2 (691 $miles^2$) of new lowland surveying has been carried out with a further 190 km^2 (73 $miles^2$) of hill land appraised by remote sensing and ground check. This has enabled all 31 sheets of the land capability for agriculture programme to be fully supported by soil surveys and has almost completed the final sheets of the lowland mapping programme. Only 200 km^2 (77 $miles^2$) of an upland fringe to Sheets 10/11 (Langholm) remain unsurveyed. Forty-three soil profiles have been added to the inventory.

Close collaboration has been maintained with DAFS regional offices throughout Scotland with five special surveys and nine other consultative reports issued. The Department has continued with a number of contracts including one new initiative, the production of the first land capability classification map for forestry, commissioned by the Nature Conservancy Council for consultations with Argyll and Bute District Council and other bodies with interests in Islay. Subsequent to this, discussions have started with the Soil Survey of England and Wales to ensure uniformity of approach to assessment of land resources for forestry.

Two items of equipment installed this year will have major implications for the Department: a Calcomp 748 flat-bed plotter and control unit, and a desk-top publishing system (Apple Macintosh Plus microcomputer and associated word processing and graphics software). The former now permits digitized 1:250 000 maps to be edited for interpretation purposes, and provides the basis for a map service personalized to customer needs. The publishing system will considerably reduce the high costs associated with short-run publications of technical nature, reduce the storage space

required for publications and allow regular updating of technical data without the wastage associated with unsold stock.

During the year Dr Rolf Tippkötter of the University of Hannover completed his micromorphological work (in association with the Department of Microbiology) and returned to Germany. Numerous delegates from foreign countries visited to discuss soil mapping and land classification techniques. The Institute display caravan was staffed at six agricultural shows and the Department contributed to the BBC programme 'Landward' on the work of the Institute.

The Department is represented on the AFRC/NERC Common Interests Group (J.S. Bibby and C.J. Bown) and its associated subgroup dealing with databases (L. Robertson); the MISR/COSAC Liaison Group (J.S. Bibby) and its subgroups dealing with Soil Survey Literature (D.W. Futty), Trace Elements (D.W. Futty) and Soil Physical Conditions (B.M. Shipley); the Ordnance Survey Public Agencies Consultative Committe (A.D. Moir); the Scottish Agricultural Field Drainage Group (B.M. Shipley) and the British Coal/DAFS Opencast Restoration Group (F.T. Dry). During the year the Aberdeen Centre for Land Use, a grouping of University and Research interests, has been formed. J.S. Bibby represents the Institute on the Management Committee. The Soil Survey has been represented on the Organizing Committee responsible for the 1987 Autumn Meeting of the British Soil Science Society and assistance has been given in planning excursions, and material contributed to the Excursion Handbook (C.J. Bown, G. Hudson).

Field Section

Methodology, Correlation and Classification

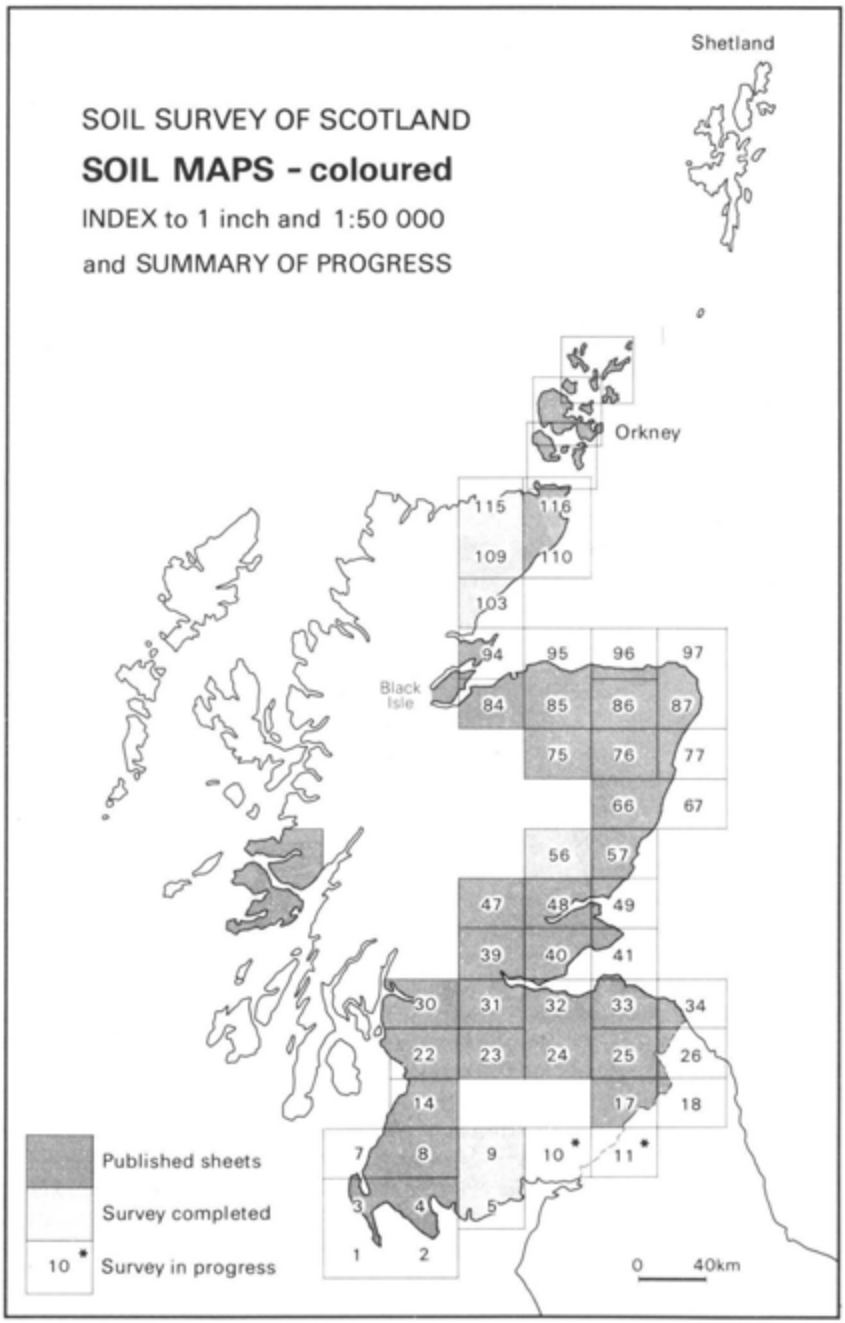
Following discussion between representatives of the Soil Survey of Scotland and that of England and Wales, a draft of a joint Field Handbook for description of soils throughout Britain has now been completed. Consideration of this draft by wider groups of intended users is being undertaken and it is anticipated that a final draft for publication will be available shortly.

Consideration of Scottish soils in relation to criteria proposed for the evolving International Reference Base for Soil Classification has been undertaken and descriptions and analyses of selected soils have been contributed to the discussions of IRB Working Group 8 on siallic soils, Working Group 12 on surface water influenced soils and Working Group 13 on podzolized soils. In addition, soil profile descriptions and analyses to exemplify the major soil units of the 1:1 million scale EEC Soil Map have been chosen and sent to the EEC Land Evaluation Steering Group.

Correlation of soil series and soil complex map units have been undertaken during survey of soils and LCA on Sheets 6 and 10 (Dumfries and Annan).

Systematic Survey

Sheets 5 and 9 (Kirkcudbright and Maxwelltown). Drafting of the final map for publication at the 1:50 000 scale is complete.


Shetland
SOIL SURVEY OF SCOTLAND
SOIL MAPS - coloured
INDEX to 1 inch and 1:50 000
and SUMMARY OF PROGRESS
Orkney
Black Isle
115
116
109
110
103
94
95
96
97
84
85
86
87
75
76
77
66
67
56
57
47
48
49
39
40
41
30
31
32
33
34
22
23
24
25
26
14
17
18
7
8
9
10
11
3
4
5
1
2
Published sheets
Survey completed
10 Survey in progress
0 40km

Sheets 6, 10 and 11 (Annan, Dumfries and Langholm). New soil survey amounted to 890 km^2 in two main districts, the first extending from Locharbriggs in the south-west, eastwards to Lockerbie and northwards into the Forest of Ae and along the Annan valley to the Coomb Burn, and the second between the River Annan and the Liddel Water south of Lockerbie and Langholm. A further 240 km^2 of predominantly upland country, occurring east and north-east of Lockerbie and extending to the River Esk at Langholm, was also completed. During the course of field-work thirty-five soil profiles were described and sampled for the National Soil Inventory.

The area south-west of Locharbriggs covers 540 km^2 and mainly has soils developed on reddish brown or red parent materials of sandy clay loam to clay loam texture mapped as the Rhins and Holywood Associations. Soils of the Holywood Association are developed on drifts derived from Permian sandstones and conglomerates and those of the Rhins Association on red-brown drifts mainly derived from Ordovician and Silurian greywackes and shales. Soils developed on yellowish brown drifts derived from the greywackes and shales belong to the Ettrick Association.

The Holywood Association occurs around Locharbriggs and the Lochmaben Basin. The principal soils are the Holywood Series (imperfectly draining brown forest soil), Craigdhu Series (freely draining brown forest soil) and the Crighton Series (freely draining brown forest soil).

Soils of the Rhins Association cover much of the land to the north and north-east of Lockerbie and west of the A74 north of Johnstonebridge. The dominant series are the Portencalzie Series (freely draining brown forest soil), the Portpatrick Series (imperfectly draining brown forest soil) and the Rhins Series (imperfectly draining brown forest soil) developed on red-brown clay loam till. The Pennyland Series (freely draining brown forest soil) developed on reddish brown shallow drift occurs on the higher, rock-controlled ground. Extensive areas of Ardwell Series (noncalcareous gley) and Glenstockdale Series (peaty gley) are found north of Johnstonebridge, in Auchenroddan Forest and on Fulton Moor. These soils occur either in low-lying areas or on gently sloping land where the till is found close to the surface. In some areas, such as Cogrie Moor, peaty gleys have been reclaimed, giving topsoils with varying organic matter contents depending on the length of time since reclamation and subsequent land use.

The soils of the Ettrick Association are generally restricted to the higher rock-controlled ground. Linhope Series (freely draining brown forest soil) is the most widespread soil of the association occurring on gently undulating land to very steep slopes, but areas of Minchmoor Series (humus-iron podzol), Dod Series (peaty podzol) and Dochroyle Series (peaty gley) are also mapped. Soil complexes are mapped on the land to the west of the Kinnel Water. The soils are predominantly peaty gleys, peat and peaty podzols with some brown forest soils and rankers. As yet many of the complex mapping units are provisional though areas of Achie Complex are widespread, but of small areal extent.

The valleys and floodplains of the River Annan, Kinnel Water, Water of Ae and Dryfe Water are occupied by alluvium and sand and gravel deposits

of the Yarrow Association. The alluvial soils are often fine textured and are moderately or imperfectly draining. Some localized areas of gravelly topsoils are found. Yarrow Series (freely draining brown forest soil) is the principal soil of the Yarrow Association. Some of this land can be very moundy as found north of Locharbriggs.

Extensive areas of basin and hill peat occur near Lochwood Moss and Redhall Moss. Peat is also a major component of soil complexes mapped on Mollin Moor and along the Kinnel Water.

About 350 km^2 of the new mapping was required, mainly in the area west of the River Annan. The fine-textured materials encountered close to the Solway Coast belong mainly to the Stirling Association, the chief soils being noncalcareous gleys; locally, coarser-textured raised beach gravels also occur. The Solway Plain is for the most part underlain by sediments of Carboniferous and Permo-Triassic ages and the soils belong mainly to the Canonbie Association, the parent material being a moderately fine-textured reddish till of mixed origin. Brown forest soils with gleying are replaced by sandier freely draining brown forest soils below 30 m altitude where water modification of the till has been intensive. North of Canonbie the drifts are greyish, derived from white Carboniferous sandstones and belong to the Carter Association. Poorly drained gleys constitute the dominant soils. The ridge of volcanic hills stretching north-westwards from Castlemilk gives rise to two further associations; the Darleith Association dominated by brown forest soils on locally derived shallow drifts from basalts, and the Kirkwood Association, the till parent material of which is a variable admixture of basalts, greywackes and sandstones of Upper Old Red Sandstone and Carboniferous ages. The soils are mainly brown forest soils with gleying. Silurian greywackes and shales give rise to shallow drifts and soils of the Ettrick Association with the brown forest soil, the Linhope Series, predominating. Deeper tills occasionally overlie these rocks and although they are apparently derived from them, the drifts have a distinct red colouration of uncertain origin; such parent materials have been assigned to the Rhins Association.

Upper raised beach and fluvioglacial sands and gravels are widespread but local in the form of mounds (Gretna and Tarcoon), eskers (Middlebie) and terraces (Ruthwell). Although the influence of local sandstone rocks on the parent materials is clear, both from the presence of sandstone fragments and their reddish colour, greywacke often dominates the >2 mm fraction and thus the soils developed on them (mainly brown forest soils of Yarrow Series) have been included within the Yarrow Association at present.

The main spreads of alluvium flank the Rivers Annan and Esk and the Mein and Kirtle Waters, the soils for the most part being freely drained with sandy silt loam or gravelly sand topsoil textures. Lowland peat soils are well represented at Branteth, Raeburn and Nutberry, and the moss at the latter locality is still being cut-over. It seems that many of the isolated remnants of raised moss occurring close to the Border were formerly more extensive, and may once have constituted a single large deposit centred on the existing Solway Moss; the topsoils of the intervening land are black and humose, indicating incorporation of organic material, most probably after removal of much of the overlying peat.

The new mapping north-east and east of Lockerbie was in an area dominated by Ordovician and Silurian greywackes and shales, giving rise to soils and soil complexes of the Ettrick Association. The Linhope Series (brown forest soils) and the Achie Complex were widespread at low elevations on gentle to steep slopes. The Dod Series (peaty podzols) is extensive on steep slopes in the hills around Langholm, and the Dochroyle Series (peaty gley) occupies the gentler slopes in the hills east of Boreland. Soils of the Rhins Association were also mapped in areas with reddish brown drifts.

Alluvial soils and sands and gravels (the Yarrow Association) were mapped along the valleys of the Dryfe Water, Water of Milk and the River Esk.

Sheet 15 (Sanquhar). Approximately 260 km^2 of new soil mapping has been completed. Efforts have been concentrated on improved and agriculturally important land which is largely restricted to the valleys and lower hill slopes. Less attention has been paid to the higher land where peat and peaty soils with limited potential for reclamation carry poor quality grazing.

The main areas mapped include the valleys of the River Ayr and Bellow Water, the valley of the lower Glenmuir Water and the plateau stretching from Avisyard Hill to Corsencon Hill, the narrow valley of the Afton Water, and the comparatively broad valley of the River Nith eastwards from Loch of the Lowes widening out in the vicinity of Kirkconnel and Sanquhar before becoming narrow near Mennock. The low ground around Durisdeer and Drumlanrig was also mapped. Most of these areas are underlain by sandstones and shales of Carboniferous age. The predominant mineral soil, a noncalcareous gley developed in a grey clay loam till, is the Rowanhill Series of the Rowanhill Association.

In the Muirkirk district red clay loam till is derived from a mixture of Carboniferous and Old Red Sandstone rocks and the soils have been included in the Sorn Association. Red clay loam parent materials are also encountered between Sanquhar and Kirkconnel, mainly on the north side of the valley. The colour in this case is derived from the underlying Barren Red Measures and the soils have been tentatively placed in the Bargour Association. Surrounding Avisyard Hill are tills including basic lava material. The soils belong to the Hindsward Association. Parent materials of these associations are fine textured with soils having low permeability. As a result noncalcareous gleys with poor drainage are the predominant mineral soil on gently or moderately sloping land. Soils with imperfect drainage are restricted to steeper or convex slopes. In some places, especially in the lowest lying sections of valleys, waterworking has resulted in soils with coarser-textured topsoils and upper subsoils which form more suitable material for regular cultivation.

South of Sanquhar, where the Nith valley narrows, the slopes are occupied by soils belonging to the Ettrick Association. Most soils are formed on shallow drift overlying greywacke and are stony and free draining. Poorly draining gleys on fine sandy loam till occur locally.

Sand and gravel mounds and terraces are encountered sporadically in the

valley floors throughout the mapped area. A high terrace mapped as the Darvel Series at Tardoes farm, Muirkirk, provides the best land for cultivation in that district, the soils being coarse textured and free draining. Around Sanquhar, terraces and mounds of gravel containing stones of greywacke and Carboniferous sandstones have been included in the Yarrow Association.

Alluvium is often of patchy occurrence and variable texture and drainage in the narrow valleys. However, between New Cumnock and Over Cairn the alluvial flat is broad and the soils predominantly silty. This stretch of land is frequently subject to severe flooding, both in winter and summer. The geology around Durisdeer is complex with Carboniferous, Permian and igneous sediments and the soil associations are provisionally ascribed. Where possible, soils of the Holywood Association were mapped on drifts derived from Permian sandstones and conglomerates, and soils of the Darleith Association on drifts from basic igneous rocks. However, where separation is not possible Durisdeer Association was mapped on drifts derived from sandstones of Permian and Carboniferous age, greywackes and basic igneous rocks. Soils of the Yarrow Association are mapped to the west of Durisdeer.

The area north of Drumlanrig Castle and west of the River Nith is a mixture of brown forest soils of the Ettrick and the Rhins Associations, depending on the colour of the drifts. On the high ground west of the Nith soils of the Ettrick Association predominate. Brown forest soils, humus-iron podzols and peaty podzols are found on the slopes, with gleys and peat on the flatter tops or in wet channels.

Sheet 16 (Moffat). Soil survey in the south-west of Sheet 16 amounted to 110 km^2 around Moffat and the upper Clyde Valley around Elvanfoot. Approximately 190 km^2 of the vegetation and soils on the hill ground were assessed by air photo interpretation and limited field observation.

The area surveyed is underlain by Ordovician and Silurian greywackes and shales, with Permian sandstone and conglomerates around Moffat and is dominated by the Ettrick, Holywood and Rhins Associations. The soils developed on reddish brown or red parent materials overlying Permian rocks have been mapped as the Holywood Association and occur in a narrow strip of country north and south of Moffat. They are surrounded by soils of the Rhins Association, which overlie greywacke and shale. Soils of the Ettrick Association are developed on yellowish brown drifts derived from the greywackes and shales and while the Rhins Association is often to be found close to areas of outcrop of the Permian rocks, the Ettrick Association is more distant. The Linhope Series (freely draining brown forest soils) and the Dod Series (peaty podzols) are mapped. Extensive areas of the Dochroyle Series (peaty gleys) were found to the north-west of Moffat. The higher land to the west of Beattock, dominated by peaty gleys, peat and peaty podzols with some brown forest soils and rankers, was mapped as soil complexes. The Trool Complex consisting of brown rankers, brown forest soils, peat and peaty gleys with rock knolls is provisionally mapped west of Moffat on the land bounded by the A74 and A701. The

valleys of the Moffat and Evan Waters and the Rivers Clyde and Annan are occupied by alluvial soils, and sands and gravels of the Yarrow Association.

Sheet 38 (Loch Lomond). Soil survey was required of approximately 150 km^2 lying to the west of soil map Sheet 39 (Stirling) published in 1965. Attention was focussed primarily on the arable land and while the soil mapping units were clearly related to those shown on the 1:250 000 Sheet 7 soil map, and this correlation assisted with the overall mapping rate, some revision was necessary. Mapping centred on two distinct areas, the western extent of the Carse of Stirling, including West Flanders Moss, and the till-covered lowlands extending between Kippen and Buchlyvie including the alluvial tract of the Endrick Water.

Although fine-textured alluvial soils flank the River Forth and the smaller watercourses, estuarine raised beach silts and clays and the remnants of raised moss peat deposits represent the most extensive soil parent materials within the Carse of Stirling. Occurring at about 15 m above sea level the estuarine materials are assigned to the Stirling Association, the dominant soil type of which is a noncalcareous gley with poor internal drainage. Soils of the Carbrook and Harviestoun Series are generally confined to distinct mounds and undulating terrain occurring at about 30 m above sea level. Where these series occur in close association with sands and gravels of the Doune Association, for example, between Arnprior and Buchlyvie, there is short-range soil variation between the imperfectly draining brown forest soils and poorly draining gleys of the fine-textured deposits and the brown forest soils with free drainage, which characterize the coarse-textured material.

Soils of two soil associations, Balrownie and Kippen, dominate the undulating till-covered lowlands and are developed on reddish brown till with sandy clay loam or sandy silt loam textures. In localized areas the Buchanyhill Series has been mapped and differs from the more widespread Balrownie Series mainly in its free natural drainage and in being developed on red sandstone rock rather than till. Variable in depth to rock, the soil usually has water-modified material between the plough horizon and underlying red sandy bedrock. Within some localities, for example around Kepdowrie Farm, the large quantity of meltwater during deglaciation has intensely modified the upper layers of the till resulting in the separation of soils assigned to the Forfar Association. Noncalcareous gleys on till are locally present and classified as the Kippendavie Series which resembles the Balrownie Series, except that it is generally a heavier soil with a clay loam till horizon and the absence of any water-modification within the subsoil. Whether the soils are developed on till or water-modified till the dominant type is a brown forest soil with gleyed B and C horizons. However, depressed sites are generally occupied by noncalcareous gley soils and, in accord with the undulating nature of the terrain, there is often a complicated pattern of soils related to differences in natural drainage.

The higher ground of Buchlyvie Muir is underlain by Lower Old Red Sandstone sediments upon which are found brown forest soils with gleyed B and C horizons. Peaty gley soils are widespread in depressed sites and often

associated with peat deposits. Where practicable the peat deposits have been separated, otherwise the pattern of soils is complicated resulting in the delineation of complex mapping units over most of the area. The valley of the Endrick Water is occupied by alluvium and by sand and gravel terrace deposits of the Carpow Association.

Sheet 55 (Aberfeldy). Soil survey was conducted along the eastern edge of Sheet 55, from Dunkeld northwards to Pitlochry, amounting to approximately 140 km^2. Within the valley of the River Tay and its tributary, the River Tummel, extensive alluvial deposits and fluvioglacial sand and gravel deposits of the Corby and Boyndie Associations were mapped, while most of the surrounding hills are underlain by acid schist rocks and are dominated by soils of the Strichen Association.

The alluvial soils along the River Tay are generally protected from flooding by earth banks and the land is amongst the most fertile in the area. Exhibiting only slight or no differentiation of pedological horizons, the soils are sandy in texture but, in some localities, comprise deep, brown sandy silt loams often overlying gravel deposits at depths of circa 100 cm. Some surface spreads of coarse gravel deposits have also been mapped. Although the alluvial soils are generally free or imperfectly drained, poorly draining sands and peaty alluvial soils have been noted within abandoned meander channels.

Spreads of fluvioglacial materials flank both sides of the valley as either mounds or distinct terraces. Thick deposits of gravel are widespread, forming the parent material of soils of the Corby Association but, in some instances, the gravel is replaced by bedded sands, often with a thin capping of gravelly sand, and soils of the Boyndie Association have been identified. Around Rotmell farm and Dalmarnock a fluvioglacial sand with a relatively high silt and fine sand content throughout the profile forms the parent material of soils assigned to the Inchewan Series (humus-iron podzol) of the Boyndie Association.

The dominant soils of the lower valley slopes are the humus-iron podzols of the Strichen and Obney Series, the parent material of which is mainly a rudely-stratified gravelly loamy sand or loamy fine sand drift rather than a compact, sandy loam or sandy silt loam till, which is generally restricted to concave slopes. Within small, natural depressions, the Hythie Series, a poorly drained peaty gley, has been identified.

Soils on hilltops and upper convex slopes are developed on both shattered rock and on coarse-textured drift which is characterized by an abundance of angular stones. Drainage is generally free and humus-iron podzols are widespread, with some peaty podzols (Gaerlie Series) on hill slopes and summits above circa 400 m. Poorly draining peaty gleys and peat occur locally, the former often on concave slopes which receive water from a series of spring lines at their upper limit, and the latter in distinct depressions or basins. Where glacial erosion has been of sufficient intensity to strip off drift cover and reveal the underlying rock, short-range soil variation is considerable and the predominant map units are soil complexes. All such soil complexes have been described previously.

Sheets 86 and 96 (Huntly and Banff). The review of the soil maps published in 1954 is nearing completion. Imperfectly drained soils have been separated, mainly using the original field-work. In the Clashindarroch area the freely drained soils of the Foudland Association on the published map have been split into humus-iron podzols (Foudland Series) and peaty podzols (Suie Series), with subalpine podzols (Ladylea Series) on the highest ground and brown forest soils (Ettenbreck Series) locally on steep slopes. Around Evron Hill the freely drained soils of the Insch Association have been classified as humus-iron podzols (Bruntland Series) in situations where peaty podzols would be expected in the Clashindarroch area. This is probably due to the higher base-status of the parent material of the Insch Association.

Other Soil Surveys

Soil Surveys have been undertaken for the Department of Agriculture and Fisheries at three proposed opencast coal extraction sites, Damside by Allanton, Black Foad by Saline and Chalmerston by Dalmellington. The objectives were:

(1) To map and describe the soils, and in particular to report on the distribution and volumes of
   (a) mineral topsoil
   (b) soil-making materials
   (c) organic material
(2) To assess the land capability for agriculture.

The soils were mapped and examined by a combination of grid survey, free survey and air photograph interpretation. The purpose of the exercise was to provide information which will assist in formulating plans for stripping and storing the soils, and subsequently for the restoration of the land.

Damside, Allanton, Motherwell District. The site at Damside occupies approximately 420 hectares. The soils were examined by grid survey based approximately on the 100 m intersections of the National Grid. The landscape is dominated by the poorly draining noncalcareous gley soils of the Rowanhill Series, and by peat. The Rowanhill Series is characterized by a slowly permeable, very coarsely structured clayey or fine loamy subsoil which generally underlies directly a mineral topsoil with a sandy silt loam or clay loam texture. The thickness of the topsoil rarely exceeds 30 centimetres.

Deep blanket peat occupies approximately 25 per cent of the site and is the principal soil of the eastern section. Most of the peat has a thickness of between 1 and 3 metres.

No practical sources of soil-making material, material with a sandy or coarse loamy texture that on restoration might replace with agronomic benefit the present slowly permeable and intractable subsoils, were mapped. A report[1] and a 1:10 000 soil map have been produced.

Black Foad, Saline, Central Region/Fife. The site and soils surveyed represent eastern and western extensions to the previously surveyed Black Foad site, an extension to the Thorny Hill opencast coal extraction site. Data were collected by a 100-metre grid survey based on the intersects of the National Grid. A total of approximately 50 hectares was surveyed.

The dominant soils are those of the Kennet Series, an imperfectly draining brown forest soil developed on water-modified tills of the Giffnock Association. The coarse-textured subsoils of these soils offer a source of soil-making materials that need be conserved.

For presentation purposes and for a whole-site overview the statistical and soils data gathered during the current survey were amalgamated with those collected during the original survey of the proposed Black Foad development.

A report[2] and a 1:10 560 soil map have been produced.

Chalmerston, Dalmellington, Cumnock and Doon Valley District. The proposed opencast coal extraction site at Chalmerston lies some two kilometres to the north-west of Dalmellington. The site is extensive and occupies approximately 8 km^2. Much of the land is in rough and hill grazings and a 200-metre grid, based on the National Grid, was adopted. The grid survey was complemented by a combination of free survey and air photograph interpretation. A report[3] and soil map have been produced.

The landscape is dominated by soils of the Rowanhill Association and by blanket peat. Soils of the Darleith Association occur locally. Within the Rowanhill Association the principal soils are the poorly draining Rowanhill Series (a noncalcareous gley) and Glaisnock Series (a peaty gley). Both soils are characterized by slowly permeable, very coarsely structured or massive, clayey or fine loamy subsoils. The Glaisnock Series has organic topsoils up to fifty centimetres in thickness. Peat is extensively developed in the northern part of the site (Headmark Moss) but also occurs more locally, often in complex soil patterns with the peaty gleys of the Glaisnock Series. The peat deposits are often hagged. The poorly draining soils of the Rowanhill Association occupy some 50 per cent of the site and peat some 17 per cent. No practical sources of soil-making materials were mapped. A considerable shortfall of mineral topsoil for restoration purposes is projected. 9012

Projects, Applications and Contracts Section

Projects

Plant Ecology Studies. Much of the field season was taken up with a land capability survey of the upland areas of Nithsdale and the Lowther Hills (Sheet 78), Lanark and Upper Nithsdale (Sheet 71) and Inverness (Sheet 26) with particular emphasis on the subdivision of Class 6 land through an interpretation of the vegetation.

Because of the geographical distribution of these three areas, a very wide range of plant communities was encountered which reflected significant differences in land use and management. The hills of the south-west around

Moffat, for example, provide some of the best natural grazings to be found in the uplands with acid or herb-rich bent-fescue grassland on the very steep valley sides (6.1g) and lower quality white bent grassland on the hill slopes and rounded summits (6.2c). To the north-west, on the hills around Wanlockhead, there is a change in management in favour of sporting interests and the landscape is heather-dominated. Humus-iron and peaty podzols underlie dry and moist Atlantic heather moor (6.3c). There is a critical increase in the amount of annual rainfall to the north of Sanquhar with a corresponding increase an the extent of blanket peat and peaty gleys and in the abundance of flying bent in the vegetation (6.3w). Although the landscape appears green, closer examination reveals that heather (*Calluna vulgaris*) and other ericaceous shrubs form an understorey to the more vigorous flying bent (*Molinia caerulea*) and bog cotton (*Eriophorum vaginatum*) and have been supressed by the heavy grazing of both sheep and cattle in this area. The vegetation is that of lowland blanket bog and, less commonly, of flying bent grassland.

There is a very marked contrast between the rolling hills of the southern uplands and the landscape to the west of Inverness, where one of the most prominent features is that of rock outcrops. This terrain is comprised of two units, a dry, heather-dominated phase with podzols and Atlantic heather moor (6.3sg) and a wet, flushed phase with peaty gleys and blanket peat supporting bog heather moor and lowland blanket bog in which deer-grass (*Trichophorum cespitosum*) is often the dominant species (6.3sw). Class 6.3 land is the most extensive by far, with some low grade 6.2 on the steep valley slopes carrying mixed birch and oakwood (6.2g) and very local patches of acid bent-fescue grassland, usually with bracken (6.1g).

A paper entitled 'Regional trends in dry and moist Scottish moorland vegetation in relation to climate, soils and other ecological factors' by A.J. Nolan and J.S. Robertson has been accepted for publication by the Journal of Ecology[4]. 9015

Micromorphology Studies. Following the return to Germany of visiting research worker Dr R. Tippkötter the section has been at a standstill due to lack of staff. Two papers prepared and submitted last year have now been published[5,6] 9804

Soil Moisture Studies. The monitoring of dip-wells located in Balrownie Series has continued. More problems in maintenance were encountered which resulted in the loss of five sites; one additional site has been installed. Some records for other sites have been discontinuous but monitoring is continuing on 32 sites. The second year's results have now been collected and are currently being appraised. They do show a regional trend but perhaps surprisingly the eastern sites are wetter than expected although still drier than the western sites. They reflect the continued wet weather of late 1985 and the generally wet spring and early summer of 1986. The sites were serviced to ensure the dip-wells began the winter period open to the proper depth and protected against damage as far as is possible with the limited resources available.

The Caithness scheme, set up to provide water-table level data for Thurso Series to assist consistent Land Capability for Agriculture classifications in the area, has continued to be relatively trouble-free with six sites still under observation. The two sites on Rowanhill Series set up on the Hartwood Experimental Farm of HFRO in Lanarkshire and observed by HFRO staff, continues into its third year. The water levels recorded and the times that they are at significant levels are less than expected in such a heavy soil. This discrepancy requires further examination.

Collaboration with staff of the North of Scotland College of Agriculture continues and the results of parts of the work on drainage guidelines for the soils of Scotland have been published[7]. 9063.

Applications

Work has continued on the preparation of maps at the 1:50 000 scale showing the capability of the land for agriculture. Field-work and comment stages from DAFS and the Colleges of Agriculture are now complete and map preparation is continuing. It is anticipated that the targets for printing will be met and that the maps will be released some months earlier than scheduled in the spring of 1987. Some limited work on other land classifications has been possible, utilizing the recently acquired plotting facilities. This facility has great promise for effective and speedy map production in the future.

Large scale surveys and consultations with DAFS staff in all regions of Scotland has continued, following the publication in March of Scottish Office News Release 0349/86 giving revised criteria for forestry planting on agricultural land which included guidance based on both soil types and agricultural land classes. Two surveys have been carried out, at Lewenshope Rig (Borders Region)[8] in connection with an application for forestry and along a section of road south of Stonehaven (Grampian Region)[9] for a road widening scheme. A total of nine other reports were compiled involving reallocation of agricultural land to alternative uses from golf courses to building (Craigie Hill and Tarhill farms (Fife Region), Newton, Monktonhill and Cockhill farms (Strathclyde Region), Tachar and Beauly (Highland Region) and Pluscarden and Broclach (Grampian Region)). Training meetings with DAFS staff have also continued. A paper on 'Land Evaluation and Site Assessment' was presented to the Engineering Group of the Geological Society at their conference in Plymouth[10]. A paper presented at a NATO conference in 1982 on land and its uses has now been published[11]. 9013

Contracts

Contracts are accepted by the Department of Soil Survey if they forward the programme of work agreed with DAFS and/or if the contract is for a public body and the Department is the only organization capable of undertaking the work because of its expertise and national overview. Five contracts were undertaken and work continued on three previously established.

Land capability classification for forestry of the Island of Islay, for the Nature Conservancy Council. A system of land classification for forestry, originally formulated by J.S. Bibby and R.E.F. Heslop at the request of the Scottish Standing Committee on Rural Land Use in 1981, but not implemented, was applied to the Island of Islay at the request of the Nature Conservancy Council as part of the Islay Review Project Plan established in consultation with Argyll and Bute District Council. The classification is founded on a premise similar to the Land Capability Classification for Agriculture and resembles that used for forestry during the Canada Land Inventory, although with emphasis on flexibility of use rather than yield. Existing soil maps at the 1:50 000 scale provided an adequate base, with which site and climatic information were combined. Topex assessments of 137 sites were made to assist characterization of shelter, a factor of major importance on Islay.

The results indicated that Classes 1 and 2 land were not represented, while Class 3 land (that capable of good growth of broadleaved as well as coniferous species) occupied only 2.4% of the island. A more restricted range of broadleaved species could be accommodated on the 14.4% of Class 4 land. Land suited primarily to spruce and pine occupied 23.6% (Class 5) while that suited to production of pine with some spruce (Class 6) occupied 49.8% of the island. Unplantable land was 9.6%. In terms of yield it was anticipated that cumulative volume production of spruce on good soils on the lowground would be some 20% less than comparable ground elsewhere in the West Conservancy of the Forestry Commission, and on poor land on the hill up to 40% less, the reductions being largely due to windthrow risk. Very wide belts of low production woodland can be expected round plantations (buffer zones), while no-thin rotations would be almost mandatory. It is significant that large proportions of the better forest land in the assessment coincided with the better agricultural land and conflict of user interests is even wider when the demands of nature conservationists and the distilling industry are taken into account. A report on the research work has been produced[12]. 9013

Assessment of soils of part of Drum Farm, West Lothian, for Steetley Refractories Ltd. At the request of Steetley Refractories Limited, Ferryhill, County Durham a soil survey of a 16-hectare site at Drum was undertaken. The purpose was to provide the Company with soils and site information which would assist in formulating plans for stripping and storing the soils and for the subsequent restoration of the land after the opencast extraction of fireclay.

The soils were examined on a 100-metre grid with supplementary points where considered necessary. A report and 1:10 000 map were produced.[13] 9012

Flow country in Caithness and Sutherland, for Fountain Forestry. Flow country was defined as peatland having the following characteristics: 1) the peat is deeper than 1m, 2) the landscape is predominantly level or gently sloping, 3) dubh-lochans are a common surface feature, and 4) there is little

or no hagging. Areas of peat with these features were delineated on 1:50 000 or 1:63 360 dyeline copies of soil maps and calculated to cover a total of approximately 90 000 ha. 9012

Loch Fleet, Dumfries and Galloway Region for South of Scotland Electricity Board. A report[14] on the soils and vegetation of the catchment has been submitted to the Electricity Board, and a summary was included in an account of the pre-intervention phase of the Loch Fleet project.[15] 9012

Blackloch Farm, Gatehouse of Fleet, Kirkcudbrightshire. A survey of the farm was carried out for the Forestry Commission. 9013

River Spey Abstraction Scheme. Agricultural Studies for Grampian Regional Council and Sir M. Macdonald and Partners. Reports on the final monitoring of water-tables within the proposed well-field were submitted. Agriculture in the area is almost entirely rain-fed. 9012

Percolation tests for drainage soakaway, Muirhead, Grampian Region. Percolation tests were carried out at Muirhead to determine the area of drainage trench and soakaway floor required to disperse effluents from a proposed septic tank and sewage filtration plant. The tests were carried out in accordance with BS (British Standards) 6297: 1983. The soils were predominantly freely drained brown forest soils of the Tarves Association, developed on drift derived from hornblende-schist. Textures of the subsoil ranged from sandy loam to loamy sand, and the rapid percolation indicated that the soil was suitable for disposal of effluents. A report[16] was produced. 9012

Domesday Project for British Broadcasting Corporation. Input to this project (see Annual Report No. 55) has been completed, with digital data on magnetic tape, together with accompanying text as hard copy, supplied to the BBC. The data sets cover soil types, land capability for agriculture, climatic regions, vegetation, type and texture of soil parent materials, soil drainage classes, topsoil textures, soil organic matter, soil acidity, cation-exchange capacity and, in conjunction with the Department of Spectrochemistry, soil copper and soil cobalt. In addition, six case-studies were contributed, covering vegetation and environment,[17] soil surveys and forestry,[18] prediction of erosion risk on ski slopes[19], the role of soil surveys in advisory drainage work,[20] the role of soil surveys in reconstitution of land after opencast coal working,[21] and soils in relation to acid rain studies.[22]

The Institute was represented at the official launch of the BBC Domesday Discs and Advanced Interactive Video System at Broadcasting House, London, in November, 1986. 9012, 9013, 9015, 9063

Publications, Cartography, Data Handling Section

Publications

Description sheets (see Annual Report No. 55) dealing with environmental factors and soil attributes have been completed for a further

48 soil map units, and 40 more have been selected for description. The 100 map units chosen cover a wide range of Scottish soils and are due for publication in 1987. 9012

Two short general accounts have been published. The first describes the soils of Sheet 56 (Blairgowrie)[23] and the second, a joint publication with the Department of Soil Fertility, covers soils and soil fertility in Caithness.[24] A third, dealing with the soils of Sheet 30 (Glasgow) is in preparation. 7043, 9012

Accounts to accompany each of the thirty-one 1:50 000 LCA maps are being prepared and drafts of eleven have been written to date. 9013

In collaboration with the Department of Spectrochemistry a booklet has been prepared illustrating the distribution of three trace elements — copper, cobalt and nickel — in Scotland. Computer-drawn plots indicate high, medium and low categories based on total amounts of each element in B horizons, and accompanying text includes comments on the distributions in relation to soil parent materials. 3007, 9012

A leaflet has been prepared which lists the kind of information held in the soil database. The purpose of this is to draw the attention of potential customers to the Institute's vast amount of data on the soils of Scotland. 1802, 3802, 8802, 9802

Cartography

Soil Maps. Sheet 30 (Glasgow)[25] has been published. A second colour proof of Sheet 103 (Golspie) has been examined and returned to Ordnance Survey for printing. A colour proof of Sheet 56 (Blairgowrie) is being checked. Sheet 109/115 (Achentoul/Reay) is with the Ordnance Survey for colour proofing.

Soil maps, scale 1:10 000, for restricted circulation were produced for five reports on special surveys, and a paper was accepted for publication in the proceedings of a meeting entitled 'Cartography — the Way Ahead' dealing with soil maps and the future of soil mapping in Scotland.[26]

Due to the amount of work required to process the 1:50 000 LCA Series, it has not been possible to produce 1:50 000 provisional Sheet 18 (Sound of Harris). It is planned to produce this sheet in the early part of 1987. 9012

1:50 000 LCA maps. The remaining 28 sheets in the series have now been compiled, and consultation with DAFS has been completed. Sheet 38 (Aberdeen), Sheet 58 (Perth and Kinross), Sheet 59 (St. Andrews and Kirkcaldy), Sheet 63 (Firth of Clyde), Sheet 64 (Glasgow), Sheet 65 (Falkirk and West Lothian), Sheet 66 (Edinburgh), Sheet 67 (Duns and Dunbar), Sheet 70 (Ayr and Kilmarnock) and Sheet 72 (Upper Clyde Valley) have been printed. Final corrections are being made by the Ordnance Survey, prior to printing, on Sheet 12 (Thurso and Wick), Sheet 30 (Fraserburgh and Peterhead), Sheet 54 (Dundee), Sheet 74 (Kelso), and Sheet 82 (Stranraer and Glen Luce). Colour proofs have been produced of Sheet 21 (Dornoch Firth), Sheet 45 (Stonehaven), Sheet 73 (Peebles and Galashiels), and Sheet 76 (Girvan). Sheet 53 (Blairgowrie) has been scribed, and a colour

proof is awaited. It is anticipated that all these sheets will be printed in the early part of 1987.

Because of the high cost and slow speed of conventional cartographic production methods, it was decided to explore the possibility of producing the final 11 sheets in the series using the Scitex computer-based system operated by John Bartholomew and Son, Edinburgh. A method of producing LCA maps partly by conventional means and partly with the Scitex system has now been devised in collaboration with Bartholomews, and a colour proof of Sheet 83 (Newton Stewart and Kirkcudbright) has been produced. Sheet 27 (Nairn), Sheet 29 (Banff), Sheet 37 (Strathdon), Sheet 71 (Lanark and Upper Nithsdale) and Sheet 78 (Nithsdale and Lowther Hills) have been scribed, and symbolling and colour seeding is in hand. Colour roughs of Sheet 57 (Stirling and The Trossachs) and Sheet 84 (Dumfries) have been produced. Sheet 26 (Inverness), Sheet 28 (Elgin) and Sheet 85 (Carlisle and Solway Firth) have been compiled. 9013

1:50 000 LCF Map. A 1:50 000 map was produced of the land capability for forestry in the island of Islay.

Digital Cartography and Single-Factor Maps. The facilities of the cartographic section have been considerably enhanced by the addition of a large Calcomp 748 flat-bed plotter and Calcomp 925 control unit. This equipment was being disposed of by BP Petroleum Development Ltd., Dyce, and was generously offered to the Department. The plotter has now been installed and recalibrated, and Calcomp Host Computer Basic Software has been debugged and installed by the Department of Statistics. A computer terminal to the Data General Eclipse minicomputer has been installed in the cartographic section, and this has aided the development of applications software to manipulate and plot the 1:250 000 digital files produced previously by Laser-Scan Laboratories. To date, the 580 soil map units have been characterized in terms of minimum cultivation requirements, vegetation and clay minerals, the latter in conjunction with the Department of Mineral Soils. Trial plots of selected areas have been successfully produced.

An Apple Macintosh Plus microcomputer, with a 20 Mb Winchester hard disk and LaserWriter printer, together with associated word-processing, graphics, Aldus 'Pagemaker' and high-level language software, has been purchased. This will aid the further development of techniques of handling digital map information. The main use of this equipment will be improved handling of the increasing numbers of publications being produced in-house and through local printers, by the section. 9012, 9013

Systems Analysis and Data Processing

The demands for a wide range of data handling facilities within the Department have continued to increase, and emphasis has been placed on field data capture techniques, automation of data handling procedures and compilation and expansion of new and existing datasets. Several

SOIL SURVEY OF SCOTLAND

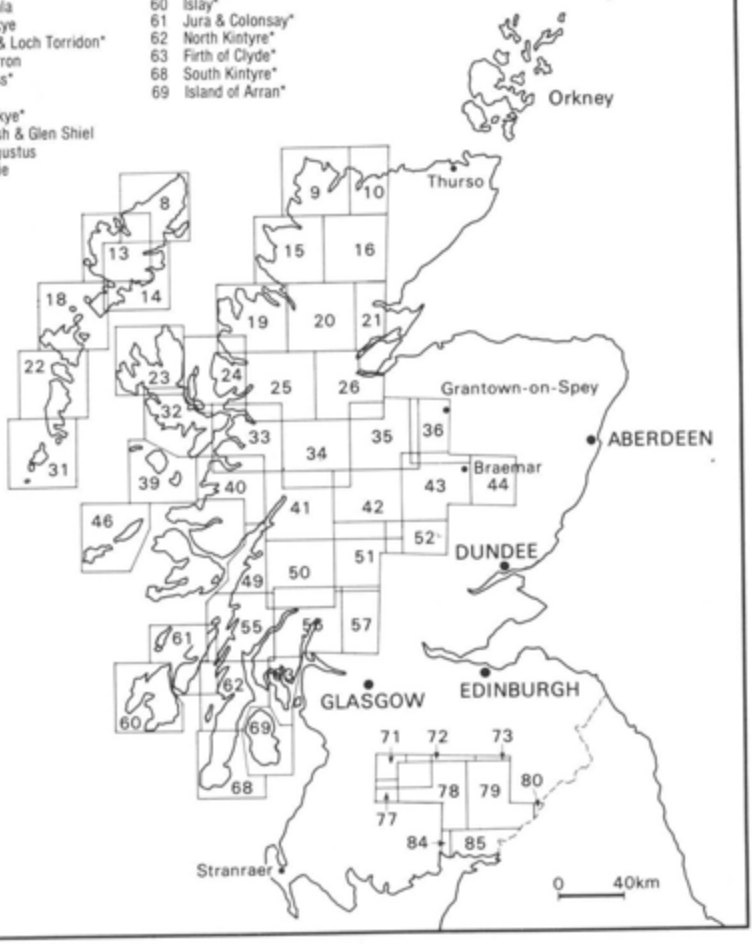
SOIL MAPS - provisional uncoloured

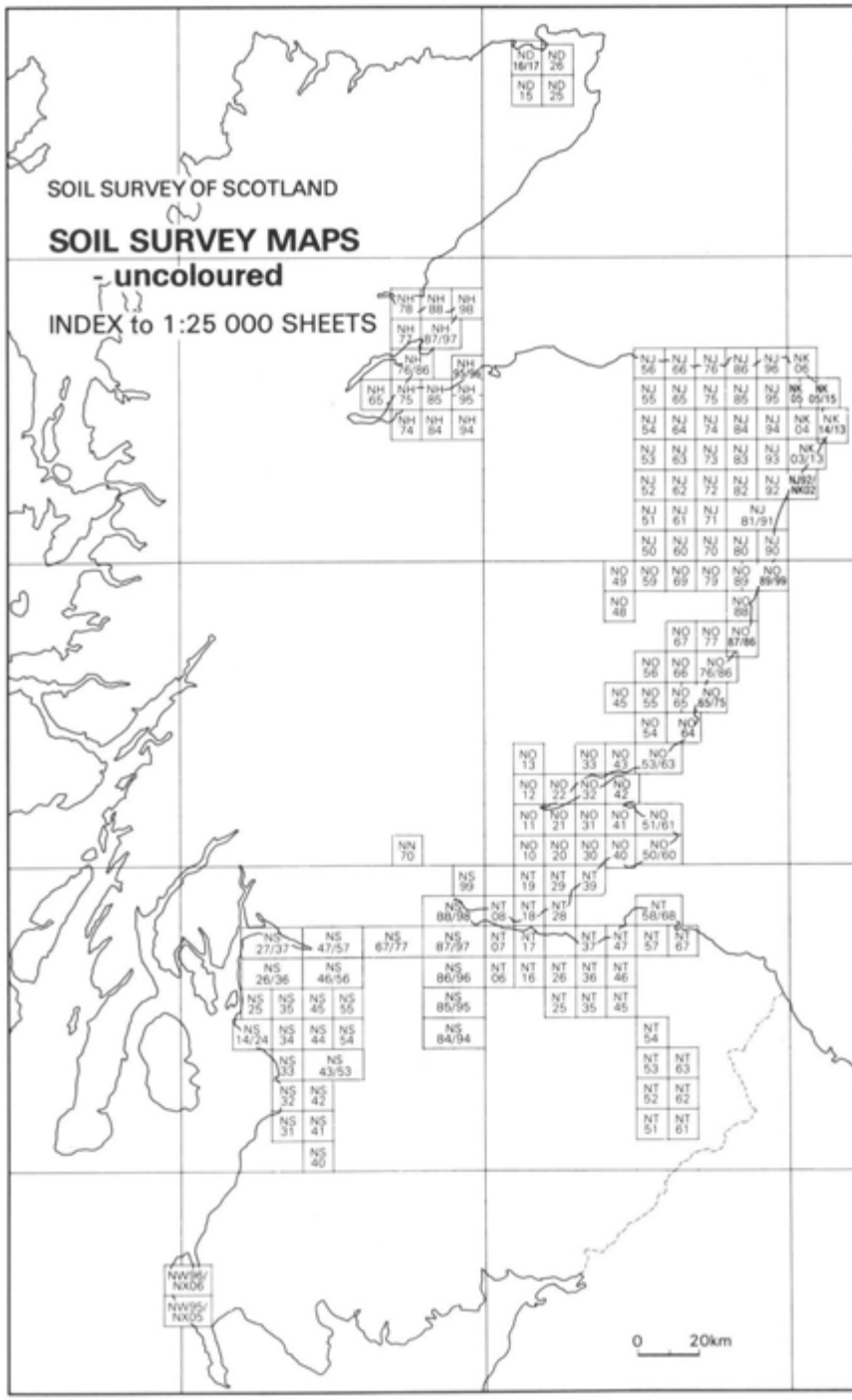
INDEX to 1:50 000 SHEETS

1 Shetland - Yell & Unst
2 Shetland - Whalsay
3 Shetland - North Mainland
4 Shetland - South Mainland
8 Stornoway & North Lewis
9 Cape Wrath
10 Strathnaver*
13 West Lewis & North Harris
14 Tarbert & Loch Seaforth
15 Loch Assynt
16 Lairg & Loch Shin*
18 Sound of Harris
19 Gairloch & Ullapool
20 Beinn Dearg
21 Dornoch Firth*
22 Benbecula
23 North Skye
24 Raasay & Loch Torridon*
25 Glen Carron
26 Inverness*
31 Barra
32 South Skye*
33 Loch Alsh & Glen Shiel
34 Fort Augustus
35 Kingussie
36 Grantown & Cairngorm*
39 Rhum & Eigg*
40 Loch Shiel*
41 Ben Nevis
42 Loch Rannoch
43 Braemar*
44 Ballater*
46 Coll & Tiree*
49 Oban & East Mull*
50 Glen Orchy
51 Loch Tay*
52 Pitlochry & Aberfeldy*
55 Lochgilphead
56 Loch Lomond*
57 Stirling & The Trossachs*
60 Islay*
61 Jura & Colonsay*
62 North Kintyre*
63 Firth of Clyde*
68 South Kintyre*
69 Island of Arran*
71 Lanark & Upper Nithsdale*
72/73 Upper Clyde Valley*/ Galashiels & Ettrick Forest*
77/78 New Galloway & Glen Trool*/ Nithsdale & Lowther Hills*
79/80 Hawick & Eskdale*/ The Cheviot Hills*
84/85 Dumfries*/ Carlisle & Solway Firth*

*indicates part sheet

o Fair Isle




SOIL SURVEY OF SCOTLAND
SOIL SURVEY MAPS
- uncoloured
INDEX to 1:25 000 SHEETS
0 20km

departmental contract applications have benefited from using Husky Hunter field-data capture techniques and associated in-house software-controlled data manipulation methods. Computer programs have been written to assist with raw data validation and preparation of summary reports and analyses.

A short case study, describing the use of microcomputers in relation to departmental soil survey applications in Scotland, has been prepared for publication.[27] (Figure 9.1)

Several items of hardware/software have been purchased during the year to improve the general data handling capability available within the department. The regional office at Inverness has been supplied with an Apple IIe microcomputer system, Epson FX100 printer and d-Base II relational database management software. A Husky Hunter portable microcomputer (352K RAM) has also been supplied for field data capture of soils and associated environmental data.

The main Apple system at Headquarters has been updated, with the addition of two 800K Unidisk drives and CP/M+ operating system, and a further Husky Hunter has been purchased, which is used extensively in connection with the transfer of data files, both to and from the Institute Data General mainframe facility. 9070

BBC Domesday Project. The completion of this project is dealt with in the 'Contracts' section of the Department's report. Considerable use has been made of the database compiled for the project by the Department, and over 100 computer-generated plots, showing the distribution of Scottish soil types and related parameters, have been prepared to assist with general research projects. 9012, 9013, 9015, 9063

Land Capability for Agriculture. A dataset holding the land capability for agriculture assessment at 1 km intersects of the National Grid is being compiled for those areas represented on the thirty-one 1:50 000 LCA maps currently in preparation. From the dataset, percentage cover occupied by each class or combination of classes is calculated, and areal distribution plots by class, class and division or limitation are being prepared. 9013, 9070

Spectrochemical and Clay distribution. In collaboration with the Departments of Spectrochemistry generalized trace element distribution plots for copper, cobalt and nickel (high, medium and low) and the percentage areal distribution of these trace element categories, based on soil association, have been prepared for Scottish soils. A similar exercise describing the distribution of kaolinite, illite and chlorite (four ranges) has also been undertaken in collaboration with the Department of Mineral Soils. 3007, 9012, 9070

Grampian Region Dataset. A soils dataset is being compiled covering Grampian Region, based on information abstracted from published 1:63 360 scale soil survey maps and other sources. Attributes presently being

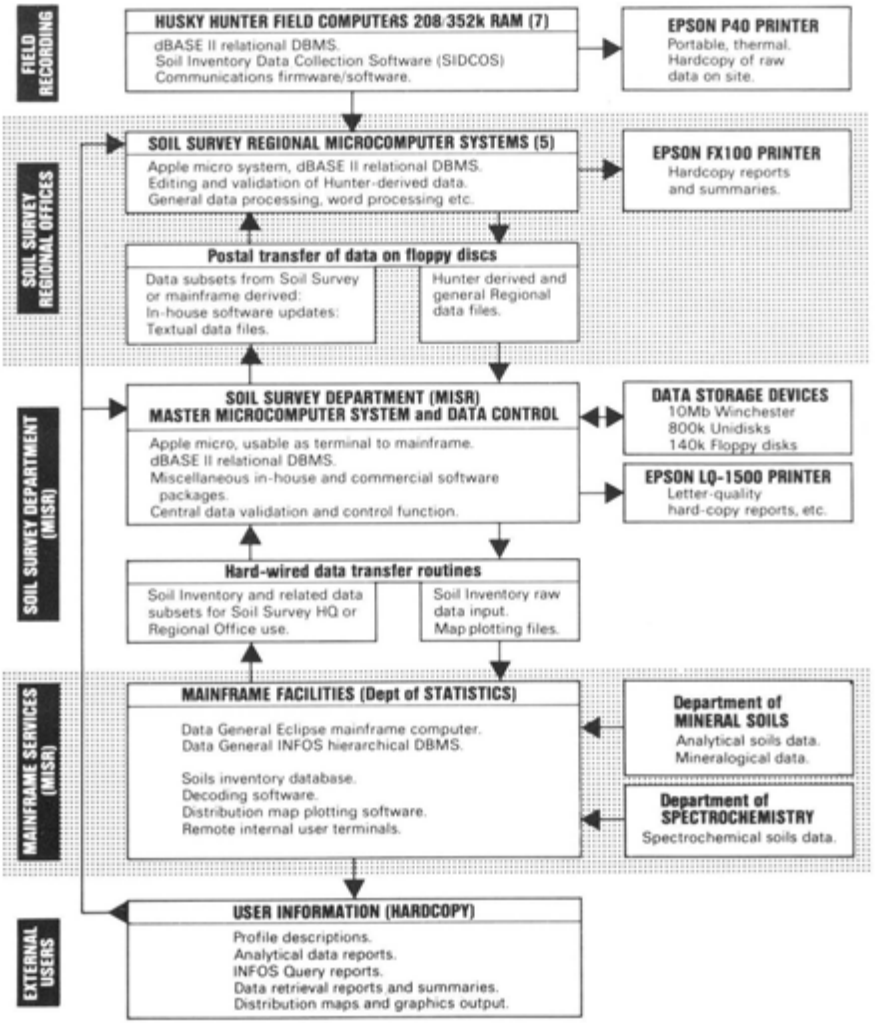


Fig. 9.1. Representation of Soil Survey data flow and hardware implementation.

recorded are soil association and series, major soil group and subgroups, soil drainage and land capability for agriculture assessment, based on a point separation of 1 km. 9070

Soil Inventory. The soil inventory database has been expanded and now holds 2175 detailed soil profile descriptions sited at the 5 and 10 km intersects of the National Grid, some 700 of which have associated analytical and chemical analyses. In addition to inventory records, profile descriptions and analyses for 1145 profiles from selected sites are held on mainframe files in a similar format. To assist with general maintenance and updating of soil survey information, copies of all the relevant files have been transferred to the Department and an Apple-based implementation of the database created using d-Base II relational database management software. 9070

References

1. The soils and land capability for agriculture of the proposed opencast coal site at Damside, Allanton, Motherwell District. By F.T. Dry and D.W. Futty. Macaulay Institute for Soil Research, 1986. (Restricted circulation.)
2. Black Foad opencast coal extraction site. By F.T. Dry. Macaulay Institute for Soil Research, 1986. (Restricted circulation.)
3. The soils and land capability for agriculture of the proposed opencast coal site at Chalmerston, Dalmellington, Cumnock and Doon Valley District. By F.T. Dry and D.W. Futty. Macaulay Institute for Soil Research, 1986. (Restricted circulation.)
4. Regional trends in dry and moist Scottish moorland vegetation in relation to climate, soils and other ecological factors. By A.J. Nolan and J.S. Robertson. To appear in *J. Ecol.*
5. The application of micromorphology to the understanding of Holocene soil development in the British Isles; with special reference to early cultivation. By R.M. Macphail, J.C.C. Romans and L. Robertson. *Proceedings of the 7th International Working Meeting on Soil Micromorphology*, Paris 1985.
6. Multi-area measurement from maps and soil thin sections using a microcomputer and graphics tablet. By L. Robertson in *Microcomputer applications in geology*. Edited by J.T. Hanley and D.F. Merriam. Vol. 5 of *Computers in Geology*. Pergamon Press, 237-255, 1986.
7. Drainage guidelines for soils in Scotland. By R.J.F. Morris and B.M. Shipley. *Soil Use and Management* 2(3), 109-114, 1986.
8. Lewenshope Rig. Soil and Land Capability Assessment. By J.S. Robertson. (Restricted circulation.)
9. The soils and land capability for agriculture classification of the proposed route of the dual carriageway extension south of Stonehaven. By A.J. Nolan. (Restricted circulation.)

10. The use of land capability and land suitability classifications for planning purposes in Scotland. By J.S. Bibby. (To be published in *Proc. of the 22nd Annual Conference of the Engineering Group of the Geological Society*, 1986.)
11. Principal features of the formation of hill land soils, their management and capability in cool, moist, temperate climates. By J.S. Bibby in *Land and its Uses — Actual and Potential. An Environmental Appraisal*. Ed. F.T. Last, M.C.B. Hotz and B.G. Bell. Plenum Press, 137-165, 1986.
12. Land capability classification for forestry of the Island of Islay, Argyll. By J.S. Bibby and R.E.F. Heslop. (Restricted circulation.)
13. The soils and land capability for agriculture of part of Drum Farm, Whitburn, West Lothian: a proposed opencast fireclay extraction site. By F.T. Dry and D.W. Futty. Macaulay Institute for Soil Research, 1986. (Restricted circulation.)
14. Soils and vegetation of the Loch Fleet catchment. Baseline studies. By G. Hudson, J.S. Robertson, C.G.B. Campbell and D.J. Henderson. Macaulay Institute for Soil Research, 1986. (Restricted circulation.)
15. Soils and vegetation of the Loch Fleet catchment. Baseline studies. By G. Hudson, J.S. Robertson, C.G.B. Campbell and D.J. Henderson in *The Loch Fleet Project. A Report of the Pre-Intervention Phase (1) 1984-1986*. Ed. by Dr Gwyneth Howells, CEGB, SSEB, NSHEB and British Coal, A1.1-A1.18, 1986.
16. Report on percolation tests carried out at Muirhead, Muir of Fowlis, Alford. By A.J. Nolan. Macaulay Institute for Soil Research, 1986. (Restricted circulation.)
17. The links between vegetation and environment in Scotland. By J.S. Robertson. *BBC Domesday Project*, 1986.
18. Soil surveys and forestry. By J.A. Hipkin. *BBC Domesday Project*, 1986.
19. Prediction of erosion risk on ski slopes. By A. Lilly. *BBC Domesday Project*, 1986.
20. Role of soil surveys in advisory work on drainage. By B.M. Shipley. *BBC Domesday Project*, 1986.
21. Role of soil surveys in reconstitution of land after opencast coal working. By C.G.B. Campbell. *BBC Domesday Project*, 1986.
22. Soil resources in environmental studies with particular reference to acid rain. By A.J. Nolan. *BBC Domesday Project*, 1986.
23. Soils of the Blairgowrie District. By J.S. Bell. Report No. 3. Macaulay Institute for Soil Research, 1986.
24. The Soils of Caithness. By W. Towers and A.H. Sinclair. Report No. 4. Macaulay Institute for Soil Research, 1986.
25. Glasgow (Sheet 30). 1:63 360 Soil. By F.T. Dry, D.J. Henderson, J.A. Hipkin, A.J. Nolan, A. Lilly and B.M. Shipley. Ordnance Survey, 1985.
26. Soil maps and the future role of Soil Survey in Scotland. By J.S. Bibby in *Cartography — The Way Ahead*. Ed. Michael Wood. In press.

27. Microcomputers in the Soil Survey of Scotland — A case study. By L. Robertson. A contribution to 'The use of microcomputers in soil survey' by P.E. Fisher and G.G. Wilkinson. Submitted for publication in *Geoderma*.

10. TECHNICAL SERVICES

A.W. STUART

All four sections of Technical Services have experienced a heavy work-load during the past year. The Photographic Unit acquired a Durst Autocolour 707 Enlarger to replace 34-year old obsolete equipment. A summary of the work undertaken by the individual Sections is given below.

Instrumentation

Peat and Forest Soils

One hundred and twenty units of a modified version of a tilting bucket unit were produced in clear perspex for the Surface Water Acidification Programme (SWAP). In addition, l0 Event and Collection Systems along with 30 modified tilting bucket units were constructed subsequently for the Norwegian site.

Spectrochemistry. Optical component mounts for Radiometers were produced for use in Remote Sensing.

Soil Fertility. Two 1 metre long soil corers, along with ancillary equipment required to extract the complete corer from the soil, and then to remove the soil sample from the corer were constructed.

Electronics

This year's work has been heavily dominated by involvement in the Surface Water Acidification Programme for which a special purpose electronic controller was developed, using CMOS technology. Altogether, nine such controllers, as well as electronic drive modules for the water samplers, have been built and used at a number of Scottish sites. A further two controllers have been prepared for use at the new site in Norway, and a description of the system is being prepared for publication.

Installation of remote computer terminals has again been necessary during the year, and a connection panel has been constructed and installed adjacent to the Data General Eclipse computer, providing the facility for any terminal to be connected either to the Eclipse or to the PAD for communication with other computing services. Devices designed to prevent unused terminals unnecessarily interrupting the computer have also been fitted.

Small automation projects have been successfully completed and much minor repair and maintenance work has been carried out, while acquisition

of an inexpensive microprocessor in-circuit emulator has provided better potential for program development, support and fault-finding on microprocessor based equipment.

Photography

The workload of the Photo Unit over the past year has been mainly routine, with the production of slides and transparencies for lectures, prints for scientific publications and exhibition work. An exceptionally heavy demand for "Poster Sessions" occurred and the need for a typesetting machine to replace typewritten material is being considered.

A short Video film was made of the work of three Departments, Microbiology, Mineral Soils and Soil Fertility, as a guide for BBC Scotland who later produced a programme in the 'Landward' series.

Aerial photography was again undertaken for the Remote Sensing Unit, in particular the Ben Achie, Howe o' the Mearns areas and Flanders Moss in the Central area of Scotland.

Support photography was given to the Department of Soil Organic Chemistry in their work on the growth analysis of seedlings. Traces from radioactive samples at the time of the Chernobyl disaster were photographed for the Department of Soil Fertility.

Joinery/Building Maintenance

Room 284A in the Department of Soil Fertility was refurbished to accommodate a F3000 Nimrod Steel (Perchloric Acid) Fume Cupboard, which also required the installation of a new fan unit on the external flat roof of the main building, to provide the appropriate extraction flow rate necessary for this type of fume cupboard.

Rooms 303 and 307 in the Department of Spectrochemistry were altered to allow the installation of a Laminar Air Flow Cabinet and the resiting of a Pye Unicam Atomic Absorption Spectrophotometer. Room 312 is at present being refurbished to provide a Positive Pressure Clean Air laboratory facility.

In the Department of Mineral Soils, Rooms 250A/250 were completely refurbished to provide additional office and laboratory space.

The upgrading of various doors and stairwells has also been undertaken as a result of visits by the Scottish Office Fire Inspector and the AFRC Safety Officer.

General Maintenance

A 155 metre track was opened to allow an external Hydro-Board electric cable to be laid to the Gardener's Cottage.

Another 30 metre track was opened to allow the installation of a further duct to carry computer lines to Outbuildings E, D and A.

Repointing work on the south facing perimeter wall is continuing at a satisfactory pace.

11. LIBRARY

A.H.W. Dickie

The Library continued to be well used by both staff and visiting research workers. It was decided to re-house departmental journal holdings in the main library, and to cancel duplicate subscriptions of journals, thus cutting costs and maximizing use of stock. The number of books bought remained almost static at 301, and 12 journals were cancelled.

Computerized literature searches increased greatly, and 53 searches were completed. More use of this service would be made if money were available.

Inter-library loans increased, both through British Library and by direct exchange. A total of 946 items were borrowed, of which 404 were through the British Library. The big increase in items lent — 298 — shows how effective the new Union Lists of Holdings are in making material available nationally at very low cost.

Two Current Awareness publications are produced — a weekly Periodicals Bulletin and a monthly Book Bulletin. They are circulated internally, and to local research institutes.

The annual List of Publications by staff was distributed internationally in the summer, and so far 1106 reprints have been sent out in response to requests. Copies of these lists and reprints are available free from the Library.

The Scottish Agricultural Librarians Group held their summer meeting at Craigiebuckler House in May. Mr Futty spoke about the work of the Soil Survey of Scotland and its publications. Later, Mr D. Anderson, of Robert Gordon's School of Librarianship, gave a talk on microcomputers in special libraries, and potential future applications of information technology.

THE ELEVENTH T.B. MACAULAY LECTURE

Aberdeen, 28th November, 1986

ACHIEVEMENTS AND PROBLEMS IN ANIMAL PRODUCTION IN THE HILLS AND UPLANDS

By John Eadie
Hill Farming Research Organization
Bush Estate, Penicuik, Midlothian
EH26 0PY

INTRODUCTION

The primary purpose of this lecture is to provide a background to the development of animal production research for those whose principal interests lie in the soil and plant sciences. It is based largely on the work of the Hill Farming Research Organisation over the years. The lecture is delivered against the background of the recent decision of DAFS to create a new Land Use Research Institute from the merger of the Hill Farming Research Organisation and the Macaulay Institute for Soil Research.

The Hill Farming Research Organisation at its inception was given a profoundly practical objective. It was charged "to conduct and promote research on the problems arising from hill farming ..... including possible methods of increasing agricultural production of sheep farming in the hills". It was recognised that this was not a simple task. An early authoritative injunction was that the Organisation "should be a pathfinder, devoting its main experimental effort to breaking down the complex of factors in the hill environment, and formulating in precise scientific terms the underlying issues".

Animal production research in the Hill Farming Research Organisation as it has developed has come to embrace a wider concept of animal production research than was perhaps envisaged in the early days. That broader concept, which I shall outline, has provided the basis upon which programmes in upland sheep, beef cattle, red deer and more recently goats have been developed, as the Organisation's remit has expanded to include the uplands as well as the hills, and less conventional as well as the traditional livestock species.

ANIMAL PERFORMANCE

In the early years of the Organisation's life the animal of study was the hill sheep. In the beginning, attention was directed primarily to individual sheep performance, and to establishing responses to the manipulation of

nutrition in the various components of whole animal performance, e.g., pregnancy nutrition as it influenced lamb birthweights, and the association of birthweights and lamb survival; reproduction and its components ovulation rate and embryo mortality; and milk yields and their influence on lamb growth rate.

Understandably at the time, early emphasis was on late pregnancy nutrition which was seen as the most pressing problem following the work of Allan Fraser in the 1930s. Much of this work took the form of large-scale experiments on the hills in a range of environments. The early work, valuable though it was in setting the scene, indicated the limitations inherent in a field approach at that time. Current feeding practices benefit from the understanding gained from a substantial series of more detailed controlled studies which have exploited the development of indices of maternal nutritional status, and methods for determining nutrient intake and absorbed nutrients in grazing sheep. Ideas have been developed about the significance of body fat reserves, the role of specific nutrients has been explored, the importance of mid-pregnancy nutrition in some environments assessed, and the value and limitations of feed blocks evaluated.

The programmes pointed the way to what has become a quiet revolution in hill sheep farming. In the early 60s very few hill sheep were hand fed in late pregnancy on a routine basis except in some areas where the frequent occurrence of deep snow often rendered the grazings inaccessible. Now the majority of hill sheep are fed as a routine practice.

More recently, a similar body of knowledge has been accumulated in respect of upland crossbreds. Estimates of foetal energy requirements in Greyface crossbred ewes agree very closely with those made for Blackfaces, and the conclusion that a moderate degree of undernourishment in crossbreds is compatible with satisfactory lamb birthweights is more than adequately underpinned with experimental evidence, and an adequate quantification of the terms "moderate undernourishment" and "adequate birthweights" has been made.

The current context in which this body of knowledge can be applied includes, again due to work in the Organisation, a practical, on-farm method of determining foetal number around the 70-100th day of pregnancy using ultrasonics, which has grown into a highly successful small industry in the 4 years or so which have elapsed since the development was first announced.

Lactation & Growth

A similar requirement both to explain differences in lamb growth and development in practice, and to improve it, led to a detailed series of studies on the nutritional manipulation of lactation performance, the consequences for lamb growth and to an understanding of the way in which milk intake, and solid-food intake, including grass, are related in the lamb. The extent and nature of the interactions of nutrition in pregnancy with that in lactation, long the subject of much argument and disagreement, were clarified. In due time, work on upland crossbreds followed that on hill

sheep, and again a good body of response information is available and has influenced profoundly the advice available to farmers.

Reproduction

Reproduction is a most powerful influence on sheep performance. Hill sheep farming is traditionally an industry of modest reproductive performance. In the Organisations's early days the high potential reproductive capability of the hill ewe was recognised, but there was a deal of confusion about the role of nutrition. Reproductive performance is influenced by a number of non-nutritional factors such as breed, age, early life nutrition, stress, etc. and studies of those factors featured in the Organisation's earlier programmes. But, the most important contribution was a clarification of nutritional effects on ovulation rate. Two aspects were recognised, one to do with previous nutrition as it influenced body condition at mating, and the other nutrition immediately prior to and during the mating period. Breed differences in response to body condition and current nutritional manipulation have been shown to exist, often in quite marked degree. This has made for an extensive series of studies of the economically important breeds and crosses in the hills and uplands, the most recent concerning those employed in Wales. These nutritional influences on ovulation rate are considerable. They carry through to lambing performance, and the industry now has at its disposal a substantial body of information, which it uses.

But the problem of embryo mortality remains much less well understood. It has not yielded to the field approach which has been so fruitful in the study of ovulation rate. It has become increasingly clear that an effective approach to the matter will only come from the acquisition of a more fundamental understanding of the physiology and endocrine control of the complex of events involving oestrus, fertilisation and implantation. In recent years the Organisation has enhanced its capability in reproductive physiology and has developed appropriate links, notably with the MRC Unit of Reproductive Biology housed in the University of Edinburgh. Good progress is being made which it is hoped will yield both understanding and techniques with which more effectively and efficiently to resolve the problem.

Beef Cattle

A very similar set of concerns, to quantify responses in the components of whole animal performance in the beef cow, has been evident in that programme.

It has been shown that the foetal calf is much less responsive to the effects of energy nutrition in the latter half of pregnancy than the lamb. Lactation performance in the single-suckling beef cow is constrained by the presence of the single calf, and milk production has been shown to be influenced to a fairly limited extent by nutrition in early lactation, whereas cow live-weight change is markedly influenced by differences in cow nutrition. Milk yields

are quite effectively maintained for example in undernourished cows and these earlier findings were very influential in determining that the interactions of body condition and level of nutrition became the focus of much subsequent work, and the reason why much effort was put into establishing the energy cost of body fat deposition and the food sparing value of fat depletion in the cow. Current concepts of beef cow management, much influenced by the results of this programme of work, are based on the manipulation of cow body condition around the annual cycle of events.

The application of this body of knowledge in practice is however seriously impeded by the fact that the spread of calving date of the beef cow in commercial herds is very wide. It is extremely difficult to allocate food efficiently, and effectively employ current knowledge, in a population of animals in the widely divergent stages implied by the calving date spread often found on the farm. Post-partum anoestrus, early embryo wastage, the foetal mortality of 8-10% found in the second and third month of pregnancy all call for attention. Collaborative work in endocrine status and ovarian follicle physiology with MRC and ABRO in relation to nutrition and management is currently under way.

Red Deer

A similar approach has again been adopted in the red deer. In pregnancy the weight of the red deer calf at birth varies with the weight of the hind at conception. Whilst severe undernourishment does have an effect, nutritional conditions in the wild appear to be adequate for reasonable calf birth weights. This is no doubt accounted for by the time of the year at which red deer hinds calve which occurs well after the beginning of the pasture growing season. A reasonable understanding of the background to good reproductive performance is available. Lactation performance in the hind is good, and very responsive indeed to nutritional manipulation. The lactation period is more extended than in the sheep. Winter inappetance, which constrains the growth of the calf in its first winter, raises special problems which have been the subject of much experimentation and some progress has been made.

Programme Development

An evolutionary trend is clearly evident in the development of these programmes focussed on individual animal performance in the range of animals studied. Initially the urgent need was simply to gain information on responses to nutritional manipulation. It was necessary to understand what was manipulable, and to what extent, and to obtain an overall perspective within which to direct future efforts.

As these more urgent needs were fulfilled the emphasis moved in two main directions. First, effort was directed towards the generation of a much better understanding of underlying mechanisms and processes. Given the wide range of resources and environments in hill and upland farming, the

problem of extrapolation puts great stress on the need to understand underlying processes. And increasingly the emphasis as knowledge accumulates will become less "problem oriented" and more concerned with the possibilites which flow from the rapidly increasing body of more basic physiological knowledge. This is likely to expand the range of possible manipulations at an increasing rate. The more we understand about the processes which link the land resources to animal performance the more likely we are to make good judgements about which manipulations are worth pursuing and in what context. It is important to bear in mind that from the point of view of land resource utilisation the ability to manipulate a particular physiological process is merely interesting. What matters in the end is the extent to which that manipulation can be employed to improve the efficiency of resource use. There is much to be done between the perception of a possibility and the employment of that possibility in the productive use of resources. Recent experience in HFRO has indicated what is involved from the work that has been done on the physiological manipulation of reproductive performance by endocrine manipulation through immunisation procedures. There will be an increasing need to evaluate the consequences to resource use of these new developments, if their potential contribution is to be properly harnessed. The pressure to move to consider lower input systems does not remove the continuing need to find ways of using resources with increasing efficiency.

A second change of emphasis has been in the extent to which it has been possible to take the response work into the field and into the grazing situation as techniques capable of contributing to the understanding of processes in free grazing ruminants have been developed. But it is perhaps necessary at this point to broaden the framework of the discussion by providing a better background to the grazing process.

RESOURCE UTILISATION

A central concern in systems of animal production from pasture is the extent to which the food supply caters for the needs of the animal population whose production is principally derived from that resource. In most pastoral environments there are very considerable irregularities of both food supply and food demand and considerable discrepancies between provision and need. Alterations to the *pattern and quality of the food supply* by pasture management, fertiliser use, pasture improvement, by conserving surpluses for later use and by supplements can all be employed. On the other side of the equation *adjustments to the pattern and quality of the demand for food* can be made by adjusting animal numbers (within limits), by changing their genotype, by altering the timing of lambing and calving, by altering animal species ratios, and by accepting and utilizing animal liveweight and body condition losses on a short-term basis. The problem has been to set these various possible manipulations firmly within a framework of understanding.

There is a fundamental need to determine the size of the livestock population appropriate to the (normally) fixed land resources of any farm

business. This can usually only be adjusted, and often only within quite narrow limits, from year to year. Within the grazing season, the allocation of parts of the whole population to specific units of land has to be determined in a way which makes sense over time. Wherever and whenever these "management" decisions are made, each one has implications for pastures in terms of their future performance, and for individual animal performance, current and future, and directly and indirectly. These requirements highlight the central importance of understanding the relationships between a given set of land resources, the size of the animal population to be catered for, and the performance of the individuals within that population. The quantification of the responses and trade offs involved, and the understanding of the underlying mechanisms and processes by which they are related fall within the definition and scope of animal production research where objectives have to do with the utilisation of pastoral resources. This precludes a simple view of animal production research in that context as a concern to learn how to manipulate individual animal performance. These manipulations, by nutritional, physiological or genetic means are part, but only part, of the task in hand. Animal production research in the context of land resource oriented objectives of HFRO is a branch of applied ecology. As such it is primarily directed at and around those levels of biological organisation which involve the whole animal, the animal population or the interactions of the animal and plant populations as the units of study.

The Hills

The almost total dependence on grazed pasture, which is characteristic of traditional hill sheep farming, limits animal output by limiting the number of animals which can be supported when the food supply is at a minimum, and at its poorest, i.e. during the winter. The size of the animal population which can reasonably accommodate this constraint inevitably results in the gross underutilisation of the available pasture feed during the height of the summer. One consequence is a dilution of the quality of the availble feed by uneaten vegetation during the pasture-growing season. The overall outcome is a combination of mediocre levels of nutrition and thus of individual animal performance, and low animal output per unit area and per unit of pasture production.

Studies of the land resources of hill and upland farming initially centred on indigenous vegetation. These studies ran contemporaneously with the earlier work focussed on individual sheep performance. They were directed towards an understanding of the ecology of a wide range of indigenous plant communities with emphasis on the better grassy vegetations. The importance of the animal in the dynamic ecology of indigenous hill pastures was appreciated from the beginning. This was followed up by the classical studies of Hunter whose earlier work on the role of the sheep in the dynamic ecology of indigenous grazings, managed in the traditional year-long free-grazing system, developed into an interest in home-range behaviour and in

its implications for animal performance. Hunter recognised the urgent need to build a bridge between studies of the land resources on the one hand and those on animal nutrition and performance on the other. The major stumbling block was a method of making the key conjoining measurement, that of the nutrient intakes of grazing animals. Faecal index methods which related the digestibility of ingested herbage to faecal constituents, and the use of animals fistulated at the oesophagus were at an early stage in their development. Unsatisfactory as they were, they nevertheless enabled a not wholly unsatisfactory attempt to describe the annual cycle of nutrition on a fairly typically mixed vegetation grassy hill to be made. From this crude beginning, together with the use of data on animal performance and responses to nutritional manipulation, it was possible to make an analysis of the traditional system of hill pasture use which brought a much clearer perspective to the role of the various possible means of manipulating the food supply and the demands for nutrient. It also provided the basis for a later synthesis.

This work stimulated attempts to evaluate that key plant community, the *Agrostis-Festuca* complex, as a source of nutrient for sheep. The evaluation was carried out using *grazing* sheep. It measured the amount of nutrient produced and the quantity and quality of the feed actually prehended by the animal and the consequences of management manipulation. That early evaluation study was followed in the early 1970s by the much more comprehensive and sophisticated evaluation of heather (*C. vulgaris*) which linked into previous work on understanding how the plant grew and developed, and on the effect of management practices (grazing and burning) on its performance. More recently, evaluation studies have continued, extending the range of communities on which there is good information to *Nardus* and *Molinia* – dominant vegetation, to blanket-bog vegetation and adding a new dimension by exploring sheep/cattle differences in the nature and quality of the ingested herbage. The development of this programme, to explore further the consequences of manipulating grazing on the dynamic ecology of the plant communities and the nutritional consequences to the animals, has anticipated the broader questions posed by the rising significance of the environmental/conservation movement. The pressures now evident to take account of the ecological consequences of the pursuit of agricultural objectives, and the need to consider a wider range of purposes for the use of animals in the hills, including the management of vegetation for landscape and wildlife objectives, will no doubt become even more pressing in the future. Further development of this aspect of the use of the hills by grazing ruminants will require an improved understanding of foraging strategies in the animal species of interest as a matter of priority and urgency.

The Uplands

The Organisation has been concerned for over a decade now with animal production from the uplands, where systems of production are much more

heavily dependent upon sown pastures, and where both livestock and pastures are under much greater management control. In the uplands there is therefore a much greater capacity and opportunity to adjust and to reduce the discrepancies between food supply and demand.

The study of the quantity and quality of feed provision from sown pastures in the uplands has taken a rather different direction to that in the hills, in response to the rather different nature of the problems. It is impractical to secure high levels of utilisation of pasture production by adjusting stock numbers within years and between seasons to an extent which effectively deals with seasonal differences in net herbage accumulation. In the hills such an objective would in any case be incompatible with the continued existence of many plant communities and often nutritionally punitive to the animal populations concerned. Again it is not physically possible to adjust feed production by the removal of surpluses for winter feed on the hills even if it were thought desirable to do so. But this latter process is possible and has become central to the efficient utilisation of sown pastures.

Pasture management is a very important determinant of both individual animal performance and of total output per unit area from pasture. This has been recognised for a long time by farmers, and is largely responsible for the huge volume of applied grassland experimentation carried out over many years in many centres around the world. It has been almost universally demonstrated that on a whole grazing season basis there are curvilinear relationships between stocking rate and individual animal performance on the one hand, and between stocking rate and total output per unit area on the other.

Much applied research effort has been devoted over the years in many agricultural research centres around the world to establishing the "local" relationships in quantitative terms. This work has not contributed very much to the development of concepts, but the effort is at least understandable in terms of the value of the information for advisory purposes, crude as it may be. It is also easy to understand the enthusiasm to explore means of increasing stock-carrying capacity by management means, and with seeking managements which might maximise individual animal performance at stocking rates which more closely approach those which maximise total animal product output per unit area. But it is much less easy in retrospect to justify the huge amount of effort which has gone into comparing different grazing management systems over the years. The hypotheses which have underpinned the management systems under investigation, where thay have existed at all, were often unclear, confused, or based on quite irrelevant considerations.

This was the situation when the Organisation's remit was extended to include the uplands as well as the hills. The potential importance of management was recognised but so also was the need for a good understanding of the relevant mechanisms and processes before proceeding to propose hypotheses about management. That understanding was developed in a series of interlinked studies dealing on the one hand with sward responses to defoliation by grazing animals, and on the other with

responses in sheep and cattle intake and its components to variations in sward conditions described in terms of mass height and density.

These studies have led to an understanding of the impact of grazing on sward responses in grass swards which puts a firm foundation under current thinking. Current thinking recognises that swards respond by adjusting tiller size and number to the severity of defoliation. That adaptation ensures that over the range of sward conditions of interest in the context of acceptable animal nutrition there is no effect on net herbage production of managements which result in quite marked differences in sward height. Nor is there any advantage over continuous grazing of more complex intermittent defoliation and rest periods. These conclusions relate to grass swards. The management of grass/clover swards requires a deeper understanding of the response to defoliation of the clover plant if the management of grass/clover swards is to be set on an equally firm foundation of understanding.

Much progress too has been made in parallel with and in interaction with those studies of sward responses in the study of the obverse side of the animal/pasture interface, where the interest has lain in animal responses to variations in sward conditions. This work has centred on intake, and the components of intake, bite size, rate of biting and grazing time in response to swards varying in mass, density and height. The results point to the dominant influence of sward height, and the central role of bite size and it now seems realistic to anticipate the framing of a unifying hypothesis to explain grazing behaviour on swards as different in structure as temperate climate ryegrass swards and the tall lax pastures of the tropics.

The magnitude of these intake responses has stimulated a re-examination of views of the relative significance of intrinsic characteristics of the ingested plant material such as digestibiliy as an index of energy concentration on the one hand, and sward conditions on the other. Within the normal range of variation encountered in both parameters in the field sward conditions as measured by height is by far the most important determinant of nutrient intake.

This work has set in place the foundations and structure of another vital bridge. As suggested earlier, a good deal had been and was being learnt about responses to nutritional manipulation in the components of performance in ruminants. This had formed a very important backdrop to an analysis of problems in and constraints upon animal performance and output from the range of pastoral resources of interest. But it had been very difficult to see how this nutritional information could be applied in practice in the grazing situation except in very general terms. The success of, and repeatability of the relationships between intake and sward conditions in grazing ecology studies encouraged the exploration of animal performance responses to variations in sward mass and height in both sheep and cattle. Good information is now available for sheep lactation and lamb growth, and for the beef cow and calf throughout the grazing season, and increasingly it is being provided for the lactating and growing deer. Uncertainties remain in respect of responses during the run up to, and over the period of mating in the sheep, but current work will undoubtedly

improve this situation in the near future. In general, however, a good understanding of the sward conditions appropriate to the various phases of the annual production cycles in sheep, cattle and red deer is now available.

It is difficult to overestimate the significance to grassland management of what has been achieved in these programmes. In the space of a few years grassland management for meat production has been transformed from an activity in which success has depended heavily on the intuitive gifts of the individual farmer, and to which science has made but a halting contribution. It has to be acknowledged that we do no better than the best of the intuitively gifted farmers. But a science-based, objective, predictable and simple set of rules promises to make efficient grassland management accessible not only to the intuitively gifted, but to all who care to learn. The advisory services have been quick to see the potential of the approach, as have many farmers. A good deal of on-farm experience is now being accumulated in the use of this approach to grassland management right across the country from Cornwall to the North of Scotland.

Grazing Studies

From the research point of view any questions which require to be addressed under grazing conditions can now be legitimately posed in an objectively detemined framework. The new Institute has a remit which will oblige it to explore some of the many second and third order interactions which arise in promoting further understanding of the soil/plant/animal complex. The conceptual problems which previously would have been very difficult to deal with in respect of experimentation involving grazing animals can now be approached with confidence and in a new light.

At an earlier stage reference was made to dietary supplements as one important means of adjusting food supply in animal production systems. Supplements have of course been a subject of study for many years, but most of the work has been done in relation to hand-fed animals held indoors. Indoor experimentation where the variables under examination can be held under tight control has made many important contributions to understanding of grazing ruminants. For many purposes however extrapolation of the findings of indoor experiments to grazing conditions is extremely hazardous. This is especially true where the precise nature of the ingested herbage diet needs to be known or has to be controlled, and where the voluntary intake of herbage is a component of the problem. Under grazing conditions supplements often act as substitutes for herbage intake, and to a highly variable extent. In getting to grips with the role of supplements in grazing systems, in resolving questions to do with their amount and composition the question of substitution has to be dealt with. The understanding now available on animal intake and performance in relation to sward conditions has provided a basis for an experimental approach in that substitution rate is known to vary with sward mass or height. It has also provided a foundation on which to base recommendations to the industry in that the need for dietary supplements can now be determined by reference to sward height. This approach has

been used very successfully in relation to supplementing upland sheep in early lactation. It is currently being used in relation to the need for information on supplementing the diet of the grazing sheep in the autumn as part of the understanding we seek to secure in relation to sward management over the sheep reproductive period.

In the past, animal production experimentation in grazing animals often foundered on complexities that prevailing methodologies could not deal with. Work in the Organisation has made a notable contribution to changing this situation. The measurement of absorbed energy substrates, microbial protein production, the amount of protein potentially available for absorption and other metabolic parameters can now be made in free-grazing sheep, with the help of automatic marker infusion, automatic body fluid sampling and isotopic tracer techniques. All of this brings within the compass of current capability access to an understanding of mechanisms and processes in the free grazing animal undreamed of even a few years ago.

Herbage intake measurement remains nonetheless a key measurement for many objectives. Much of value has been accomplished by faecal index methods, by those based on supposedly indigestible markers and by the use of oesophageal fistulates but the search for methods of acceptable accuracy, free of biases of an unpredictable nature, continues. A new chapter has been opened in the continuing story by the conception and development of a most elegant and promising technique based on the odd chain alkanes of the cutins and waxes of herbage. The potential of this approach bids fair to remove many of the limitations of existing techniques and to add a much-needed ability to determine the composition of the diet derived from mixed species swards. This opens a new door on the study of grass/clover swards, and of diet selection between and within indigenous plant communitites.

SYSTEMS STUDIES

Systems studies have been a major feature of HFRO's research for many years. It is not necessary to believe Whitehead's axiom that each whole is more than the sums of its parts to believe that systems research is a *sine qua non* of research in pasture based animal production. Which is perhaps just as well, since Whitehead's axiom is now thought to be more than a little damaged by the implications of advances in the understanding of a whole series of fundamental processes. But the argument is philosophical rather than scientific in nature and will doubtless continue.

The ultimate objective of much research is to illuminate and inform decision making in the real world. These decisions have to do with the integration of resources in whole and continuing systems, and with the operation of these systems in an objective and predictable fashion. In the present state of knowledge of animal production systems from the rather complex combinations of land resources of the hills and uplands, it is not quite possible at this stage to put the components together to produce an adequate mathematical model. Part of the reason for this is lack of knowledge of the components, and that kind of deficiency is, within the limits of the understanding of processes at a more fundamental level and of

appropriate techniques, amenable to resolution. The implications of nutrition during lactation for body condition recovery in the ewe and the implication of that, in turn, for ovulation rate are understood. But there are many such implications of current events for future performance and it is just not possible to give quantitative expression to them all with sufficient certainty at the present time. But the main reason is that, in the systems under study, populations of plants and populations of animals interact over time in a most complex way which includes a whole series of feedback loops. Gigantic strides have been made in conceptualising and quantifying the whole but the point has not yet been reached at which a mathematical model could be constructed which would be of real value for research pruposes — that is for providing insights into important relationships at the whole systems level. The need to do so is great. The time is fast approaching when it will be possible — but that time is not yet.

Animal production systems studies in HFRO to date have been real world, on-the-ground practical programmes. They take a different form and have different objectives in the hills compared to the uplands and have come about in different ways in these two environments.

Hills

A stage was reached at which it was possible to make a convincing analysis of traditional hill sheep farming based on indigenous pastures. That analysis and the response information had been accumulated on nutrition and performance in hill sheep was later integrated into a convincing hypothesis of how to effect a very considerable improvement in output.

It was decided to put it to the test at Sourhope on a grassy hill. Some time later is was examined and suitably amended on blanket peat at Lephinmore. The same basic idea was adapted at a later date to take account of the findings of research on heather moorland at Glensaugh. The principles were taken up by WCSA at Kirkton and ADAS at Redesdale. It became the subject of a joint HFRO/Scottish Colleges programme on private farms. It has been a very successful concept, increasing output by several fold in a financially acceptable way wherever it has been appropriately applied and well-managed.

The NEDC included the whole process from conception to joint HFRO/College project to uptake in an investigation of the Adoption of Technology in Agriculture in 1985. The report highlighted the multidisciplinary nature of the development, and emphasised the crucial role played by the systems approach and the fact that the development by the Institute concerned had included this phase in its own development of the idea.

Since the approach was developed however, capital grants have been vastly reduced and the agricultural world has been somewhat turned on its head. It remains valid and appropriate in some circumstances but the scope for its widespread application has been much reduced. But the experience has resulted in a much enhanced capability to think about this complex activity, the experience to handle it on the gournd, and a vast amount of

data which gives a very sharp insight into a wide range of important relationships. All of this will be put to good use when a clearer indication of the financial and policy framework within which the future of animal production from indigenous pastures will have to be approached becomes available.

Uplands

More recently, as a result of the work already described on the various aspects of grazing by sheep and cattle, it is now possible to gear the management of grassland in upland sheep and cattle systems to a grazing-season-long profile of herbage height. It is possible to achieve that profile in practice by means of a series of interlinked, objectively-based decision rules which govern among other things the timing of and the area of land from which surpluses are removed for conservation. It is possible to deal with the feed-back from the summer period in terms of herbage surpluses conserved as hay/silage in a further set of decision rules which also deal with the need for and employment of feed from outwith the system, thus a whole system can be described in objective terms by means of an integrated series of decision rules, each rule founded on a relevant aspect of the biology of the system.

Systems based on this approach have been operated with considerable success now for several years. They have been used to quantify relationships between overall stocking rate, sheep performance and nitrogen use — information which cannot be obtained by means of studies other than those at the systems level. Patterns of N use have also been explored and the methodology has also been used to provide a valid experimental framework within which to investigate the significance of differences in herbage varieties to animal output and sheep performance, and the implications of the components of genotypic differences in the sheep such as size and reproductive performance. It is currently being used to explore the land resource use implications of genotypic differences in nutrient partition in beef cows.

A whole range of questions, some of which are of great practical importance, and others whose concern is to enhance further an understanding of the biology of grazing systems, can now be posed in an experimentally legitimate fashion, and directly.

Progress in understanding at the systems level is quite crucial to success in achieving objectives in a land resource oriented Institute. One of the exciting potentials of the new Institute is the possibility it provides for developing understanding of the behaviour of whole systems and their responses to perturbation in areas in which knowledge is lacking. Many aspects of soil/plant interrelations for example require to be taken account of in ways that have not so far been possible. The experience of HFRO suggests that the way to do this is through the direct involvement of the scientists concerned with the more usual analytical approach to the acquisition of new understanding and information in the processes of integrating their unique understanding of particular processes into the wider

quantitative picture. Systems studies are not the province of systems specialists. They are for everybody.

Farm/forestry integration

Several years ago HFRO broadened its systems interests to address the question of land allocation as between conventional high conifer forestry and hill sheep production. The approach was based on the assessment of the land resources both for forestry and for sheep farming on a grid of appropriate size. A set of allocation rules was developed with which to make the land allocation. These rules are applied to examine the consequences of several assumptions about the size and nature of the remaining farm enterprise, and the outcome when the better or the poorer land was devoted to forestry. The output is calculated in financial terms and a net benefit index computed to provide a feel for the extent to which an individual solution generates more or less economic activity than the original farm enterprise, or in relation to planting the whole of the unit.

The object was not to develop a computerised decision making machine, but rather to provide a means of giving people a quantitatively based feel for a range of possibilities from which they may then proceed towards an acceptable solution taking account of their specific requirements. The philosophy built into this approach is very important.

An examination of the application of this approach has shown that there are in many situations integrated solutions where the net benefit to integration exceeds that of either of the monocultures. But they have to be looked for. They do not pop out in relation to some obvious and recognisable feature like soil type, vegetation, or altitude, although all of these exert an important influence. It is vital to good land use decision making to have a good understanding of the biology of the systems of interest. But it would be naive to believe that land use decision making can be based simply on characterising land resources in appropriate terms. It is generally true that differences in soil and vegetation characteristics feed through the processes which influence output. But when it comes to making choices between alternative land uses, or to integrating them, there are many non-biological factors which have a profound influence on the costs of making the changes involved in the new objective. These will often dominate the outcome of the decision making process if it is to make any concessions to economic reality, as such decisions surely must. The improvement of the characterisation of resources and a better understanding of the biological relationships built into the models employed will be an important outcome of future work. But its impact on decision making in the real world will also depend on how efffectively the long overdue need to integrate biology and economics is met.

Recent Developments

Also on the subject of animal production in interaction with forestry, HFRO has in recent times developed an interest and much activity in

agroforestry. There is a very real need to underpin this potentially very important development with a good scientific understanding in a range of areas. The coming together of HFRO and MISR on aspects of nutrient cycling in the agroforesty context is a particularly welcome development, and a growth point from which hopefully much more will spring. We cannot wait 55 or 60 years for direct experience throughout the lifetime of a forest production cycle. The processes will have to be modelled, and the scientific challenge is a very real and exciting one.

On yet another front there is a rapidly developing need for an explicit awareness in terms that all concerned, whether they be farmers or conservationists, can understand of the processes involved in and the outcome of changes in vegetation management on open-hill vegetation. Models can fulfill such a purpose. It is perhaps fortuitous that the strong public interest in the visual amenity of heather coincides with a good understanding of its grazing management, together with good data of an animal nutritional and ecological kind on the interactions of heather and *agrostis-fescue* vegetation. The heather/*agrostis fescue* resource is about the simplest situation for which management models will be required for a future in which production and landscape/environment objectives may well have to exist in a different balance to that of the past. The processes involved in developing the heather/agrostis model have done much to sharpen an awareness of the nature of the information required to fulfill the needs of the future.

CONCLUSION

Animal performance research in the Hill Farming Research Organisation began with the study of the responses of the sheep to nutritional manipulation. The work has since included the beef cow and calf, the red deer, and most recently the goat. It would be reasonable to say that the response quantification phase is now fairly fully documented. Much of it is now translatable in terms of the grazing situation.

The future may well lie more with the exploration of exploitable possiblities than with the solution of problems. Many of these exploitable possiblities will be less concerned with nutritional manipulation and much more with increasingly sophisticated means of physiological manipulation. Increased knowledge of the range of nutritional environments in which animal production takes place in the hills and uplands and of the responses of existing genotypes has undoubtedly sharpened an appreciation of the characteristics required of successful genotypes. Animal genetics has become increasingly concerned with developing the capability to manipulate. Animal science relevant to the future uses of the hills and uplands will become increasingly concerned with the purposes to which that capability may be put.

On the broader front of animal production the scene is set for the most exciting and productive phase in the advance of knowledge that animal production from pastures, whether these be complex arrays of indigenous plant communities or sown pastures, has yet known. Concepts have been

developed and the techniques are there to make this so. The context in which new knowledge must be sought has widened to include the integration of animal production with landscape and amenity objectives, and with objectives which take account of the resource needs of wildlife in its many forms. It includes the integration of animal production systems with forestry systems and a range of possible agroforestries. It has aiso widened to include the less traditional livestock species both individually and in integration one with another.

Animal production will undoubtedly continue to provide a key means by which economic activity is generated in the hills and uplands. The new Institute concept will enhance the range and depth of the skills and capabilities which will be required to underpin a future which will be more diverse in terms of objectives, products and systems. It will also provide the essential framework within which these skills and capabilitites can be integrated in a purposeful way. Part of its promise stems from the fact that many of the crucial processes determining the output of animal product from the land resources of interest of the new Institute can only be properly understood in terms of soil/plant/animal interactions.

ACKNOWLEDGEMENTS

This lecture is based on the work of many HFRO colleagues, past and present. Their individual contributions are readily accessible in the earlier series of HFRO Triennial Reports and in the more recent series of Biennial Reports. The views expressed and the philosophy of the Organisation's approach to its work have similarly been influenced by many colleagues over the years to whom I give my grateful thanks. I am particularly indebted to those Heads of Department with whom I have worked most closely in recent years, Dr Peter Newbould, Dr Jeff Maxwell, Dr John Hodgson and Dr John Milne.

APPENDIX II

VISITS ABROAD — 1986

	Place/Event	*Lectures*	*Date — 1986*	*Financed by*
1. H.A. Anderson	Oslo (Norway) International Humic Substances Society Third International Meeting	1	August	DAFS
2. H.A. Anderson	Hoylandet (Norway) Visit to examine proposed SWAP site	—	June	SWAP
3. J.S. Anderson	Hoylandet (Norway) Installation of monitoring equipment for SWAP	—	September	SWAP
4. D. Atkinson	Michigan (USA) Michigan State University Fruit School	9	January/ February	MSU
5. D. Atkinson	Martinsburg (USA) West Virginian Horticultural Society Annual Convention + USDA Kearneysville Research Station	2	February	WVHS/USDA
6. D.C. Bain	Hamburg (Federal Republic of Germany) XIII Congress of the International Society of Soil Science	—	August	DAFS
7. R.G. Baker	Abisco (Sweden) Workshop on Functional Aspects of Carbon Accumulation	1	September	Conference Organisers/ British Council/Self
8. M.L. Berrow	Brussels (Belgium) Community Bureau of Reference	—	April	EEC
9. M.L. Berrow	Lisbon (Portugal) International Conference, Chemicals in the Environment	1	July	Conference Organisers
10. M.L. Berrow	Hamburg (Federal Republic of Germany) XIII Congress of the International Society of Soil Science	1	August	DAFS
11. R.V. Birnie	Oberjettenberg (Federal Republic of Germany) Radar Field Trials	—	February	University of Aberdeen
12. C.D. Campbell	Nancy (France) Visit to Microbiology Laboratory, University of Nancy	1	March	Society of General Microbiology
13. M.V. Cheshire	Hamburg (Federal Republic of Germany) XIII Congress of the International Society of Soil Science	1	August	DAFS
14. M.V. Cheshire	Santiago (Spain) Visit to the Department of Soil Biochemistry, Institute for Agrobiological Research	1	September	National Research Council of Spain and British Council
15. J.F. Darbyshire	Ljubljana (Yugoslavia) V International Symposium on Microbial Ecology	1	August	DAFS
16. R.C. Ferrier	Hoylandet (Norway) Installation of monitoring equipment for SWAP	—	September	SWAP

	Place/Event	*Lectures*	*Date — 1985*	*Financed by*
17. B.A. Goodman	Oslo (Norway) International Humic Substances Society Third International Meeting	1	August	DAFS
18. B.A. Goodman	Ghent (Belgium) NATO-ISSS Advanced Research Workshop on "Interactions at the Soil-Colloid Soil Solution Interface"	—	August	NATO/Self
19. A. Hepburn	Hoylandet (Norway) Installation of monitoring equipment for SWAP	—	September	SWAP
20. P.D. Hulme	Lammi, Jyvaskyla, Oulanka, Oulu, Helsinki (Finland) Mires Research Group Field Meeting	—	August	DAFS/British Ecological Society
21. D. Jones	Arlington (USA) V International Symposium on Biomineralization at University of Texas (UTA)	1	May	Self & UTA
22. L. Mackie	Hamburg (Federal Republic of Germany) XIII Congress of the International Society of Soil Science	—	August	DAFS
23. P. Millard	Hamburg (Federal Republic of Germany) 5th Congress of the Federation of European Societies of Plant Physiology, University of Hamburg	—	September	DAFS
24. J.D. Miller	Hoylandet (Norway) Visit potential SWAP instrumentation sites	—	June	SWAP
25. J.D. Miller	Hoylandet (Norway) Installation of monitoring equipment for SWAP	—	September	SWAP
26. M.F. Proe	Uppsala (Sweden) Workshop on Predicting Consequences of Intensive Forest Harvesting on Long-Term Productivity	1	May	Swedish University of Agricultural Sciences
27. J.S. Robertson	Wageningen (Netherlands) Fourth European Ecological Symposium	1	September	DAFS
28. A.H. Sinclair	Hamburg (Feberal Republic of Germany) XIII Congress of the International Society of Soil Science	—	August	DAFS
29. A.M. Ure	Dublin (Eire) Chemistry Society of Ireland	1	May	Chemical Society of Ireland
30. D. Vaughan	Milan (Italy) Meeting on The contribution of humic substances to the soil and their action on plant growth organised by Enichem Agriculture	1	March	Enichem Agriculture
31. T.S. West	Delhi (India) IUPAC Officers' Conference	—	March	IUPAC
32. T.S. West	Bern (Switzerland) ICSU General Assembly	—	September	ICSU/Royal Society
33. B.L. Williams	Hamburg (Federal Republic of Germany) XIII Congress of the International Society of Soil Science + Post-congress tour of the peatlands of north-west Germany and the Netherlands	—	August	DAFS

	Place/Event	*Lectures*	*Date* — 1985	*Financed by*
34. M.J. Wilson	Knoxville, Tennessee (USA) Workshop on Acid Deposition and Weathering	—	May	EPRI, EPA, NCASI
35. M.J. Wilson	Hoylandet, North Tronderlag (Norway) Visit to catchment	—	June	SWAP

APPENDIX III
LECTURES GIVEN IN THE U.K. BY MEMBERS OF STAFF

	Place	*Event*	*Date — 1986*
Department of Mineral Soils			
M.J. Wilson	Grange-over-Sands	Merlewood Research Station. Meeting on Terrestrial Ecosystem Nutrient Cycling	December
	Bangor	University College of North Wales, Department of Soil Science & Biochemistry	November
	Cumbernauld	Loch Fleet Meeting	April
	Aberdeen	University of Aberdeen, Department of Soil Science	April
W.J. McHardy	Aberdeen	Electron Microscope Users Group	February
	Cambridge	Cambridge Instruments International SEM Users Conference.	April
	Aberdeen	University of Aberdeen, Department of Soil Science	February
B.F.L. Smith	Dalry	Loch Fleet Open Day Meeting	September
J.M. Bracewell	Reading	7th International Symposium on Analytical and Applied Pyrolysis	September
	Aberdeen	University of Aberdeen, Department of Soil Science	February
E. Paterson	Aberdeen	University of Aberdeen, Department of Soil Science	February
Department of Peat and Forest Soils			
R.V. Birnie	Silsoe	Silsoe College MSc in Applied Remote Sensing	January
P.D. Hulme	Edinburgh	Mires Research Group	February
A.F. Leech	Cumbernauld	Loch Fleet Open Meeting	April
T.F. Nisbet	Cumbernauld	Loch Fleet Open Meeting	April
M.F. Proe	Fochabers	Forestry Commission Nursery Managers Meeting	April
G.G. Wright	Aberdeen	Institute of Civil Engineers	May

	Place	*Event*	*Date* - 1985
Department of Spectrochemistry			
M.L. Berrow	London	4th European Meeting of the Society for Environmental Geochemistry & Health	April
B.A. Goodman	Lancaster	Geocolloids Group Meeting: Sorption processes in geocolloid systems	April
B.L. Sharp	Loughborough	Royal Society of Chemistry. Post - Experience Course on Inductively Coupled Plasmas	September
C.A. Shand	Bristol	International Conference on Analytical Chemistry — SAC83/3rd BNASS	July
Mrs M.C. Mitchell	Bristol	International Conference on Analytical Chemistry — SAC83/3rd BNASS	July
Department of Soil Organic Chemistry			
D.C. Gordon	Stirling	Scottish Plant Physiology Group Meeting	March
I.R. MacDonald	Bristol	Tenth Long Ashton Research Symposium	September
	Aberdeen	Aberdeen University Department of Plant Science	October
Department of Plant Physiology			
J.A. Armstrong	Merlewood	ITE Symposium on Nutrient Cycling	December
A.E.S. Macklon	York	Plant Transport Group 1st Meeting	April
Department of Microbiology			
D. Jones	Bangor	Mineralogical Society Meeting on Clay Minerals and Biological Processes	March
	London	Royal Microscopical Society Micro-86 and Eurosem 86 meeting	July
	Manchester	XIV International Congress of Microbiology	September
R.E. Wheatley	Manchester	XIV Internationl Congress of Microbiology	September
Department of Soil Fertility			
D. Atkinson	Edzell	University of Aberdeen Soil Science residential conference	November

	Place	*Event*	*Date* - 1985
	Wye College University of London		November
	Aberdeen	Institute of Groundsmen	December
L.A. Mackie	Cambridge	Meeting of the Association of Applied Biologists on crop protection of sugar beet, crop protection and quality of potatoes	December
	Aberdeen	Department of Soil Science University of Aberdeen colloquia	December
	Stoneleigh	Royal Agricultural Show	July
P. Millard	Nottingham	SEB Conference on Nitrogen Cycling in higher plants	March
	Dundee	Department Crop Protection and Physiology Seminar	March
D. Robinson	Dundee	University, Biological Sciences departmental seminar	March
	Aberdeen	University, Botanical of Edinburgh, invited lecture	March
	Sheffield	University, Botany departmental seminar	March
	Stirling	University, Botanical Society of Edinburgh, invited lecture	April
	St Andrews	University, Botanical Society of Edinburgh, invited lecture	April
	Edinburgh	University, Botanical Society of Edinburgh, invited lecture	April
	London	AFRC Modellers' Group meeting	April
	Glasgow	University, Botanical Society of Edinburgh, invited lecture	April
	Aberdeen	University, Soil Science departmental seminar	May
	Aberdeen	NOSCA/MISR Nitrogen Conference	September

	Grange-over-Sands	Symposium on Field Methods in Terrestrial Ecosystem Nutrient Cycling	December
A.H. Sinclair	Aberdeen	Turriff Rotary Club	June
	Aberdeen	Aberdeen Probus Club	June
	Orkney	Orkney Agricultural Discussion Group	October
	Tarland	North-East Nurserymen Management Course	December
	Turriff to Aberdeen	Farmer Discussion Groups	
Department of Soil Survey			
J.S. Bibby	Plymouth	Engineering Group of Geological Society 22 Annual Conference	September
F.T. Dry	Symington	Field Course for DAFS staff	September
D.W. Futty	Aberdeen	Scottish Agricultural Librarians Group	May
	Edinburgh	Scottish Association of Geography Teachers	October
J.H. Gauld	Perth	Perth Round Table	November
	Perth	Perth Agricultural Discussion Group	December
	Dunkeld	Field course for DAFS staff	October
R.E.F. Heslop	Aberdeen	NOSCA HND Students Course	March
	Clinterty	Aberdeen University Soil Science Excursion	May
	Huntly	Field Course for DAFS staff	June
	Aberdeen	Aberdeen University MSc course in Ecology	October
A. Lilly	Clinterty	Aberdeen University Soil Science Excursion	May
	Glen Dye	Aberdeen University Soil Science Excursion	May
	Huntly	Field course for DAFS staff	June
	Craibstone	Agricultural Training Board	September
A.D. Moir	Aberdeen	British Cartographic Society	January
A.J. Nolan	Aberdeen	NOSCA HND Students course	March
	Clinterty	Aberdeen University of Soil Science Excursion	May
	Glen Dye	Aberdeen University Soil Science Excursion	May
	Huntly	Field course for DAFS staff	June
J.S. Robertson	Various	Ten field course for DAFS staff	June-Sept.
	Cumbernauld	Loch Fleet project. Open meeting	April
W. Towers	Strath Conon	Field course for DAFS staff	June
	Rogart	Field course for DAFS staff	June

PUBLICATIONS
1986

The numbers appearing on the left-hand side of this list are the MISR serial numbers for the items. Please quote these numbers when asking for reprints from the Librarian, Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen, AB9 2QJ. *Reprints with no serial numbers are only available if priced.* Items marked* are publications of the Department of Soil Survey, and can be bought from them at the above address. Current Price Lists are available from both the Department of Soil Survey and the Librarian.

ADAMS, M.J., BIRNIE, R.V. and WRIGHT, G.G. Portable radiometers for monitoring crop growth. *MISR Technical Note No.9* Aberdeen, Macaulay Institute for Soil Research, 1986.

ANDERSON, H.A. and HEPBURN, A. Variation of humic substances within peat profiles. In *Peat and Water: aspects of water retention and dewatering in peat.* Edited by C.A. Fuchsman. London, Elsevier, 1986, 147-194.
The sources of humic substances in peats are discussed, with special reference to the polysaccharide and lignin contributions. Acid hydrolysis of humic acids derived from fen peat and hill peat profiles show that these substances have a low degree of humification, with no indication of any "secondary" polysaccharide content. Ratios of phenolic acids in the hydrolysates also suggest less humification than that found in organic horizons of podzols.

ANDERSON, H.A. and HEPBURN, A. Biochemical and other soil analyses. In *The pit alignment at Eskbank Nurseries* By J. Barber. *Proc. Prehistoric Society*, 1985, **57**, 149-166.
Soil samples from supposed Iron Age post-holes at Eskbank show dominant features typical of the surrounding arable soils, especially in their high pH, calcium-bound humus and high organic phosphate contents. While the vanillic:4-hydroxybenzoic acid ratios of the humus are within a grass/sedge category of origin, the low degree of humification demonstrated is also shown by authentic post-hole soils from the Bannockburn area. These latter soils, typically, show a low organic phosphate contribution to a very high total phosphate content.

ATKINSON, D. The nutrient requirements of fruit trees:some current considerations. *Adv. Plant Nutr.*, 1986, **2**, 93-128.
The needs of fruit trees for mineral nutrients and the ways in which they differ from other crops in their needs for nutrients are discussed. Discussion is focussed upon the importances of the timing of new root growth in relation to phosphorous uptake and upon the effects of the ability of the tree to conserve nutrients from year to year and recycle them within the tree. Mineral nutrition is reviewed both in the context of the growing tree and the need to produce fruit with a specified nutrient content so as to ensure good storage properties.

ATKINSON, D. Options for orchard floor management. *Mountaineer Grower, 1986,* **467**, 11-23.
A range of methods for managing the soil in orchards are reviewed and related to their effects on water and nutrient supply to trees. Soil management systems must allow good access to the trees, effective exploitation of soil by the tree root system and good water and nutrient supply. Basic considerations like these are modified by orchard type, soil type and climatic factors. Soils managed with herbicides maximize water and nutrient supply to the tree, but can result in adverse effects on physical properties. Where soils are managed with a grass cover the competition between the grass and the trees can be modified by selection of appropriate grass variety and the use of plant growth regulators.

ATKINSON, D. Producing quality fruit-water and nutrient supply. *Mountaineer Grower*, 1986, **463**, 3-15.
The paper reviews the effects of water and nutrient supply to fruit trees on the quality of the fruit that they produce. Nutrient and water supply are discussed in relation to characteristics of the tree root system such as root length density, periodicity of root growth and root distribution. The presence of a sufficient root

length at critical times in fruit development is seen as vital for the nutrient supply needed for good fruit storage qualities. Poor early season root growth seemed related to fruit with a low phosphorous content. The overall low root length density found in apple means that in some circumstances methods of relieving water stress other than soil applied irrigation would be needed. Mist application, when water is applied to the leaves to reduce transpiration has been effective in this way.

1422 ATKINSON, D. Effect of some plant growth regulators on water use and the uptake of mineral nutrients by tree crops. *Acta Hort*, 1986, **179**, 395-404.
The direct and indirect effects of plant growth regulators (PGRs) on mineral nutrition and water use are reviewed, with particular attention to the effects of paclobutrazol on tree crops. Paclobutrazol and other retardants reduce water consumption as a result of effects on leaf area. Stomatal conductivity is often reduced and, as a result, especially where plants are under stress, water potential is increased. Under field conditions effects seem likely to be smaller than for experiments in pots. In intensive systems paclobutrazol may reduce root length and density and hence the use of soil resources. Effects of retardants on nutrient concentrations are usually smaller than those on growth.

BACON, J.R. Multi-element analysis of kidney and liver samples by spark source mass spectrometry. *Adv. Mass Spectr.*, 1986, **10**, 1277-1278.
Spark source mass spectrometric procedures have been standardised for the analysis of biological materials and results for a horse kidney sample are compared to those obtained by other techniques. Data are presented for the trace element determination of ten foetal kidney samples and compared with published data for human foetal kidney, human adult kidney and human foetal liver samples.

1414 BAIN, D.C., BERROW, M.L., McHARDY, W.J., PATERSON, E., RUSSELL, J.D., SHARP, B.L., URE, A.M. and WEST, T.S. Optical, electron and X-ray spectrometry in soil analysis. *Anal. Chim. Acta.*, 1986, **180**, 163-185.
Advances in knowledge of the structure and behaviour of soils depend largely on the application of various techniques of spectrometry. Elemental techniques such as emission spectrography, radiofrequency plasma emission spectrometry, atomic absorption spectrometry and X-ray fluorescence spectrometry have made major contributions in this area. Surface examination techniques such as electron beam microanalysis and, more recently, photo and X-ray induced electron spectrometry (ESCA/XPS) have yielded much new information on the fertility and field behaviour of soils. In the area of structural examination, infra-red absorption spectrometry is a particularly useful technique in relation to both the organic and inorganic structures present in soils.

BAKER, R.G.E. and MACKLON, A.E.S. A study of factors affecting the growth and morphology of *sphagnum*. Final Report to the Highlands and Islands Development Board, 1986. (Restricted circulation).

BBC DOMESDAY PROJECT.
The links between vegetation and environment in Scotland. By J.S. Robertson.
Soil surveys and forestry. By J.A. Hipkin.
Prediction of erosion risk on ski slopes. By A. Lilly.
Role of soil surveys in advisory work on drainage. By B.M. Shipley.
Role of soil surveys in reconstitution of land after opencast coal working. By C.G.B. Campbell.
Soil resources in environmental studies with particular reference to acid rain. By A.J. Nolan.
London, B.B.C., 1986.

*BELL, J.S. Soils of the Blairgowrie District. *MISR Report No.3* Aberdeen, Macaulay Institute for Soil Research, 1986. £1.00.

BENZING-PURDIE, L., CHESHIRE, M.V., WILLIAMS, B.L., SPARLING, G.P., RATCLIFFE, C.I. and RIPMEESTER, J.A. Fate of ^{15}N-glycine in peat as determined by ^{13}C and ^{15}N CP-MAS NMR spectroscopy. *J. Agric. Fd. Chem.*, 1986, **34**, 170-176.

Soil humic substances, in many respects, resemble melanoidins, the brown, high molecular weight polymers produced by the reaction of carbohydrates and amino acids. Formation of melanoidins in blanket peat has been studied by incubating samples with ^{15}N labelled glycine and using CP-MAS NMR spectroscopy to identify the chemical environments of ^{13}C and ^{15}N atoms. As the reaction in question is purely chemical, glycine was added to both sterile and non-sterile peat. Separation of the peat into different particle size fractions after incubation enabled a comparison of the extent of the reaction in components with different degrees of humification. Spectral peaks commensurate with the presence of melanoidins were seen in all incubated samples, but particularly in peat sterilized by irradiation or autoclaving.

BERROW, M.L. An overview of soil contamination problems. *Proc. Int. Conf. Chemicals in the Environment, Lisbon, 1986.* London, Selper Ltd., 1986, 543-552.
Soil contamination by inorganic elements can arise from many sources including beneficial agricultural additives and other materials such as sewage sludge, compost, fly ash and mine waste and atmospheric deposition. Contamination from these sources is largely caused by Man's activities and their relative importance is discussed. Contamination of soil by organic pollutants also arises from agricultural and industrial sources but is generally much less persistent than that by inorganic elements, particularly the heavy metals. Background levels and guidelines for the control of metal contaminations of soils are considered. Further information is needed before guidelines to control the amounts of harmful organic residues in soil can be adopted.

BERROW, M.L. Soil trace element maps. *MISR Technical Note No. 6.* Aberdeen, Macaulay Institute for Soil Research, 1986.

BERROW, M.L. and DAVIDSON, M.S. The use of 2-ketogluconic acid in soil profile trace element studies. *Trans. Congr. Int. Soc. Soil Sci., 13th, Hamburg, 1986,* **2**, 239-240.
The use of 2-ketogluconic acid, a naturally occurring acid produced by soil bacteria in the rhizosphere, as a soil extractant in soil profile trace element studies was investigated. The 2-ketogluconic acid extracted much less cobalt, copper, iron, manganese, nickel, vanadium and zinc than EDTA or DTPA at pH 7.0 from organic horizons.
Considerably more copper, iron, lead, titanium and vanadium was extracted by 2-ketogluconic acid than by ammonium acetate at the same pH indicating that 2-ketogluconic acid chelates a portion of the non-exchangeable forms of these elements in the soil.

1398 BERROW, M.L. and REAVES, G.A. Total chromium and nickel contents of Scottish soils. *Geoderma*, 1986, **37**, 15-27.
The frequency distributions of chromium and nickel contents in Scottish soils are reported and the relation of the concentrations to some other soil variables is examined. The derived mean for chromium is 62 and the normal range 5.4-710 mg/kg; the corresponding figures for nickel are 27 and 3.4-210 mg/kg. The concentrations of these two elements show a high degree of correlation ($r = 0.83$) and the form of the relationships between element content and other soil variables is very similar in both cases. Element concentrations are greater in soils derived from basic and intermediate igneous than in those derived from acid igneous rocks and greater in fine-textured than in sandy sediments. Concentrations decrease with increasing sand and organic matter contents but show relatively little variation with increase in depth below 10 cm. Topsoil contents are generally lower than subsoil contents especially where the organic matter content is high.

1406 BERROW, M.L. and URE, A.M. Trace element distribution and mobilization in Scottish soils with particular reference to cobalt, copper and molybdenum. *Environm. Geochem. Health*, 1986, **8**, 19-24.
The distribution of trace elements in Scottish soils is discussed and the influence of such factors as soil parent material, texture, organic matter content and environmental contamination on soil contents is examined. The relationship between total and extractable contents in soils is also discussed in relation to the

use of total contents for soil trace element mapping. The importance of soil drainage class and its influence on the extractable amounts of trace elements in Scottish soils is illustrated and the effects of soil drainage on the uptake of such important trace elements as cobalt, copper and molybdenum by herbage is also discussed.

BERROW, M.L. and URE, A.M. Relationships between trace element availability and the soils and geology of the Aberdeen area. *Proc. Int. Symp. Trace Element Metabolism in Man and Animals, 5th, Aberdeen, 1984.* Slough, CAB, 1985, 841-843.
The close similarity of the total element contents of parent rocks and those of their derived soils is illustrated by examples from the Aberdeen area. The B-horizons of soils derived from granite and fluvioglacial sands and gravels consistently contain low levels of cobalt and copper and deficiences of these elements arise typically on such soils. Abnormally high molybdenum contents are found in soils from localized areas derived from particular rock types. The influence of factors other than parent material such as soil drainage status, texture and pH on the availability of cobalt, copper and molybdenum to plants and hence to animals is also reported.

1409 BIBBY, J.S. Principal features of the formation of hill land soils; their management and capability in cool, moist, temperate climates. In *Land: its uses-actual and potential: Proc. NATO Seminar on Land and its Uses, Edinburgh, 1982.* New York, Plenum, 1986, 137-165.
The paper confines itself largely to Scottish soil conditions and is divided into two parts:
i) the hill land environment, particularly in relation to the soil-forming processes of climate, geology, landform and the distribution of major soil types. It describes properties of soil for planners in non-technical terms (mineral and organic surfaces, dry and wet soils). It ends with a description of soil patterns and the degree of variation in map units.
ii) land and the land user, which concentrates on soil properties as they affect agriculture and forestry. The land classification for agriculture is described and the fact that there is not a similar product for forestry criticized. The section ends with two case studies of the use of soil information in planning, one at the farm level (Melfort Estates, part of the HFRO-COSAC two-paddock management system investigation) and one at regional level (HIDB Mull Development Plan). It is concluded that soil information and investigations are an essential part of the planners' studies.

BIBBY, J.S. and HESLOP, R.E.F. Land capability classification for forestry of the Island of Islay, Argyll. (Restricted circulation).

1416 BIRNIE, A.C., CLARK, D.R. and PATERSON, E. A semi-micro method for the examination of selected soil components by transmission electron microscopy. *Clay Miner.*, 1986, **21**, 231-234.
The oxides of iron and manganese are important indicators of the internal drainage status of a soil but, because of their sporadic occurrence in the profile, they are difficult to sample and characterise. In this paper a method is described by which they may be isolated from the soil matrix in a relatively pure form and subsequently characterised by transmission electron microscopy. Some examples of the usefulness of the method are reported.

1415 BIRNIE, R.V. Pixel mixing effects and their significance to identifying snow condition from LANDSAT MSS data. *Int. J. Remote Sensing.*, 1986, **7**, 845-853.
Evidence is presented which suggests that pixel mixing effects, rather than changing snow conditions, may be an alternative explanation of the systematic variation observed over snow-covered terrain on LANDSAT MSS images.

1408 BIRNIE, R.V. and MILLER, D.R. The bracken problem in Scotland: a new assessment using remotely sensed data. In *Bracken: ecology, land use and control technology: Proc. Bracken 85.* Carnforth, Parthenon Publishing, 1986, 43-55.
This paper presents a progress report upon a DAFS-sponsored project to map the extent and the rate of spread of bracken in Scottish hill land. The methods and

results of a pilot study are outlined and the development of a survey methodology for a national mapping programme is described with reference to its recent application to a test site in Argyll.

1373 BURRIDGE, J.C. and HEWITT, I.J. Coprecipitation of microgram amounts of lead and tin with aluminium, using 8-hydroxyquinoline, tannic acid and either thionalide or sodium sulphide. *Analyst*, 1985, **110**, 795-800.
The use of sodium sulphide in place of thionalide, for the coprecipitation of trace elements with aluminium by the procedure introduced by Mitchell and Scott in the 1940's, has been studied with emphasis on the recovery of lead. This has established that only about 50-70% of lead, in the range 15-150mg, is recovered by the procedure with thionalide, whereas a complete recovery is obtained with sodium sulphide. Calibration curves for the direc -current carbon-arc derived from mixed-powder standards for lead, tin and iron differed significantly from those obtained with precipitated standards. The precipitation of tin with 8-hydroxyquinoline alone appeared to be more complete than was previously suggested, but some loss of tin occurred during other stages of the procedure.

1394 BURRIDGE, J.C. and HEWITT, I.J. Determination of aluminium in soil extracts by carbon arc emission spectrometry after coprecipitation with iron using 8-hydroxyquinoline. *J. Anal. Atomic Spectr.*, 1986, **1**, 41-44.
Coprecipitation of aluminium with iron, followed by an analysis of the ignited precipitate ($Fe_2 0_3$) in a carbon arc is described. Acetic-acid and ammonium-acetate soil extracts were used to demonstrate that amounts of at least 5μg A1 in up to 200 ml of extract could be determined with a relative standard deviation of about 3%. The soil contents ranged from over 1000 μg A1 g^{-1} soil extracted by acetic acid, to less than 1 μg A1 g^{-1} soil extracted by ammonium acetate.

1404 BURRIDGE, J.C., HEWITT, I.J. and ANDERSON, H.A. 2'-Mercapto-4-*n*-propylacetanilide: an alternative to thionalide for precipitating lead from weak acid solution. *Analyst*, 1986, **111**, 253-254.
Several compounds containing the thioglycolic acid group (-NH.CO.CH.SH) were prepared and tested as substitutes for thionalide in the procedure developed by Scott and Mitchell for precipitating trace elements prior to carbon-arc spectrographic analysis. One of these compounds, 2'-mercapto-4-propylacetanilide, gave better recoveries of lead (75%) than were obtainable with thionalide (55%). In situations where a complete recovery of lead, for example by using sodium sulphide, is not essential, this new reagent can be substituted for thionalide with advantage.

CAMPBELL, C.D., DARBYSHIRE, J.F. and ANDERSON, J.G. Microbial decomposition of coniferous tree bark. *Int. Congress Microbiol ., 14th, Manchester, 1986*. Abstract P. B313-23, 84.

CAMPBELL, C.D., DARBYSHIRE, J.F. and ANDERSON, J.G. Growth and fruiting body formation of *Plerotus cornucopiae* on composted conifer bark. *Int. Congress Microbiol., 14th, Manchester, 1986*.
Abstract P. B13-24, 84.

CHAPMAN, S.J. Microbial biomass sulphur in some Scottish soils. *Int. Congress Microbiol., 14th, Manchester, 1986*. Abstract P.G8-1, 283.

CHESHIRE, M.V., INKSON, R.H.E. and MUNDIE, C.M. Decomposition of the carbohydrates of ryegrass and straw in soil. *Trans. Int. Soil Science Soc. Congress, 13th, Hamburg, 1986*, 563-564.
Mathematical expressions have been devised for the rate of decomposition of ^{14}C labelled carbohydrate materials during incubation in soil. The rate of decomposition of the major sugar components of straw and ryegrass leaf was best expressed by two or three part exponential functions of the form y= a;e $^{-6}$ i'.

1386 CHESHIRE, M.V., GOODMAN, B.A., McPHAIL, D.B. and SPARLING, G.P. Electron paramagnetic resonance characteristics of the humic acids from a podzol. *Organic Geochem.*, 1985, **8**, 427-440.

A study has been made of solid and solution electron spin resonance (EPR) spectra of humic acids from different horizons in a podzolic soil. Hyperfine splitting was observed in the solution spectra of humic acids from all horizons and depended on the strength of alkali and the period of dissolution. The upper organic horizons L, F and O, contained humic acids with some spectral characteristics in common with lignin. Humic acid from the lower horizons showed different spectra. At least 5 different radical signals were present.

CRESSER, M.S., EBDON, L.C., McLEOD, C.W. and BURRIDGE, J.C. Atomic spectrometry update-environmental analysis. *J. Anal. At. Spectrom.*, 1986, **1**, 1R-17R.

DRY, F.T. Black Foad opencast coal extraction site. (Restricted circulation).

DRY, F.T. and FUTTY, D.W. The soils and land capability for agriculture of part of Drum Farm, Whitburn, West Lothian: a proposed opencast fireclay extraction site. (Restricted circulation).

DRY, F.T. and FUTTY, D.W. The soils and land capability for agriculture of the proposed opencast coal site at Damside, Allanton, Motherwell District. (Restricted circulation).

DRY, F.T. and FUTTY, D.W. The soils and land capability for agriculture of the proposed opencast coal site at Chalmerston, Dalmellington, Cumnock and Doon Valley District. (Restricted circulation).

EBDON, L.C., GREENFIELD, S. and SHARP, B.L. The versatile inductively coupled plasma. *Chem. Brit.*, 1985, **22**, 123-130.

EDWARDS, A.C. and KILLHAM, K. The effects of freeze/thaw on gaseous nitrogen loss from upland soils. *Soil Use Manage.*, 1986, **2**, 86-91.
The effect of a short-term freeze/thaw cycle (15°C to −8°C to 15°C) on gaseous N-loss (denitrification and NH^3-volatilization) from intact bolocks of an upland soil is described. Rates of both denitrification and NH^3-volatilization were increased by the freeze/thaw cycle, particularly when the blocks had previously been fertilized with urea. Increased gaseous N-loss due to freeze/thaw is reported for soils under heather and under improved grass pasture.

EDWARDS, A.C., CREASEY, J. and CRESSER, M.S. Factors influencing nitrogen inputs and outputs in two Scottish upland catchments. *Soil Use Manage.*, 1986, **1**, 83-87.
The factors influencing nitrogen inputs in wet deposition in two upland catchments in northeast Scotland are discussed. Seasonal trends in nitrate-nitrogen concentrations in water draining from the catchments, and in monthly nitrate-nitrogen outputs, are reported and explained. The inputs in rain exceed the output in the rivers in the two catchments by 3.9-9.4 kg ha^{-1} a^{-1}. Retention by vegetation probably plays a crucial role in nitrogen cycling in the uplands.

EDWARDS, A.C., CREASEY, J. and CRESSER, M.S. Soil freezing effects on upland stream solute chemistry. *Water Res.*, 1986, **20**, 831-834.
Freeze-thaw cycles may have a significant effect upon both soil and surface water chemistry. Observed trends in river water solute levels during spring have been related to leachate obtained from organic soils which have undergone a freeze-thaw cycle. Increased amounts of leachable aluminium, potassium and organic carbon in particular were noted after the freeze-thaw treatment.

1379 FARMER, V.C. The aromaticity of soil fulvic acid: response to comments by M. Schnitzer. *Nature*, 1985, **313**, 458-463.
Sharp aromatic resonances reported in the ^{13}C NMR spectrum of methylated fulvic acid probably arise from contaminants. They cannot be ascribed to an effect of methylation on the aromatic carbon of fulvic acid. Yields of benzene and hydrobenzene polycarboxylic acids identified in the oxidation products of fulvic acid in Schnitzer's laboratories are anomalously high, compared with those obtained elsewhere. The ^{13}C NMR spectrum of the unfractionated oxidation products from peracetic acid oxidation of fulvic acid show that benzene

polycarboxylic acids cannot be present in the amounts reported by Schnitzer and Skinner.

FARMER, V.C. Sources and speciation of aluminium and silicon in natural waters. *Silicon Biochemistry. Ciba Foundation Symposium No. 121, 1986.*
This paper summarizes the factors that control the release of aluminium and silicon from silicate minerals, and traces their fate in the environment. Particular emphasis is placed on the metastable weathering products that are widespread in acid soils of the temperate and boreal climate zones, as they form reservoirs of readily soluble aluminium and silicon, which can then be taken up by plants and imbibed by animals. Current knowledge of the concentrations and speciation of Al and Si in natural waters is briefly reviewed.

FRASER, S.M., EDMONDS, T.E. and WEST, T.S. Development of a multi-sensor system using coated piezoelectric crystal detectors. *Analyst*, 1986, **111**, 1183-88.

1393 FRASER, S.M., URE, A.M. MITCHELL, M.C. and WEST, T.S. Determination of cadmium in calcium chloride extracts of soils by atom-trapping atomic absorption spectrometry. *J. Anal. At. Spectr.*, 1986, **1**, 19-21.
A method is described for the determination of cadmium in 0.05 M calcium chloride extracts of soils by atom trapping atomic absorption spectrometry. The technique of atom trapping atomic absorption has been applied to such determinations of cadmium as the levels encountered are too low for detection by conventional flame atomic absorption. A study of the effect of interference from major elements present in the extracts demonstrates that this method is relatively free from interference problems. The method has been applied to the determination of cadmium in a number of Scottish top soils.

GORDON, J.E. and BIRNIE, R.V. Production and transfer of subaerially generated rock debris and resulting landforms on South Georgia: an introductory perspective. *Brit. Antarct. Surv. Bull.*, 1986, **(72)**, 25-46.

1396 GRIFFITHS, B.S. and ALEXANDER, C.E. A technique for culturing enchytraeid worms on coniferous litter. *Soil Biol. Biochem.*, 1986, **18**, 123-124.
A technique was developed for culturing enchytraeid worms on coniferous litter. The method has potential for studying enchytraeid biology, or for culturing large numbers of worms for experimental purposes.

1397 GRIFFITHS, B.S. and WOOD, S. Microorganisms associated with the hindgut of *Oniscus asellus*. (Crustacea, Isopoda). *Pedobiol.*, 1985, **28**, 377-381.
The hindgut of the woodlouse *Oniscus asellus* contained an average of 2.66×10^5 bacteria mg^{-1} and 3.73×10^4 actinomycetes mg^{-1}. Scanning electron and light microscopy demonstrated the presence of rod-shaped bacteria, adherent to the hindgut cuticle. The commonest organism was identified as *Enterobacter agglomerans* and when inoculated onto hindgut cuticle grew more rapidly than cells of *Pseudomonas fluorescens*. The sparse distribution of the adherent bacteria makes it unlikely that they are important in organic matter degradation.

HUDSON, G., ROBERTSON, J.S., CAMPBELL, C.G.B. and HENDERSON, D.J. Soils and vegetation of the Loch Fleet catchment. (Baseline studies.) (Restricted circulation).

HUDSON, G., ROBERTSON, J.S., CAMPBELL, C.G.B. and HENDERSON, D.J. Soils and vegetation of the Loch Fleet catchment. (Baseline studies.) In *The Loch Fleet Project: a report of the pre-intervention phase (1) 1984-86.* Edited by G. Howells. Leatherhead, CEGB, 1986, A1.1-A1.18.

1411 HULME, P.D. The origin and development of wet hollows and pools on Craigeazle Mire, South-West Scotland. *Int. Peat J.*, 1986, **1**, 15-28.
This paper describes some of the features and processes associated with wet hollows and pool formation on patterned peatland. Investigations into peat stratigraphy, hydrology, chemistry and bulk density and *sphagnum* production are presented.

HULME, P.D. and BLYTH, A.W. An investigation of the peat deposits of Highgreen Estate, Northumberland. A Report for Highgreen Estate. (Restricted circulation.)

1418 JONES, D. amd WILSON, M.J. Biomineralization in crustose lichens. *Proc. Int. Symp. Biomineralization in Lower Plants and Animals, Birmingham, 1985.* Oxford, Clarendon Press, 1986, 91-105.
Rock-inhibiting crustose lichens are now known to have marked weathering effects on the mineral constituents of their substrates. One of the effects of such processes results in the accumulation of crystalline organic salts in the lichen thallus. It is largely this aspect of biomineralization that will be discussed and presented in this review, but in addition reference will be made to the formation of similar products in free-living fungi in an attempt to explain the processes in saxicolous lichens since one of the partners in the symbiotic relationship in the lichen thallus is a fungus (mycobiont). Lichens are regarded as primitive mycorrhiza (fungi associated with plant roots) and consequently studies on them may shed light on weathering of minerals in soil and uptake of metals by plant roots.

JONES, D., ALEXANDER, C.E. and McHARDY, W.J. SEM of cryofixed mycorrhizas. *Int. Congress Microbiol., 14th, Manchester, 1986.* Abstract P.M3-1, 149.

JONES, D., ALEXANDER, C.E. and McHARDY, W.J. Scanning electron microscopy of cryofixed mycorrhiza of Sitka spruce (Picea sitchensis) and other selected mycological specimens. *Proc. R. Soc. Microsc. Soc.*, 1986, **21**, S87.

JONES, D., WILSON, M.J. and RUSSELL, J.D. Characterization of crystals of vermiculine from shake cultures of *Talaromyces wortmanii. Int. Congress Microbiol., 14th, Manchester, 1986.* Abstract P.G4-2, 245.

JONES, D., ANDERSON, H.A., RUSSELL, J.D., FRASER, A.R., HEPBURN, A. and ONIONS, A.H.S. 5-hydroxymaltol, a secondary metabolite from *Penicillium echinulatum* Fassatiora spec. nov. *Int. Congress Microbiol., 14th, Manchester, 1986.* Abstract P.G4-1.

LEECH, A.F. Changes in rainwater chemistry on passage through a forested ecosystem at Loch Fleet, Galloway. In: *The Loch Fleet Project: a report of the pre-intervention phase (1) 1984-86.* Leatherhead, CEGB, 1986, A4.1-4.8.

McHARDY, W.J. Are interstratified clays aggregates of more fundamental particles? *Proc. Symp. Clays and the Origin of Life, Glasgow, 1983.* London, C.U.P., 1986, 52-57.
An explanation for the X-ray diffraction patterns of interstratified clays is advanced on the basis of the extreme thinness of the individual crystals involved. This model regards interstratified clay minerals as aggregates of only three types of fundamental particles whose X-ray diffraction patterns result from interparticle diffraction. This new interpretation of the phenomenon of interstratification has implications in regard to theories on the diagenetic conversion of smectite to illite.

1417 McKEAGUE, J.A., CHESHIRE, M.V., ANDREUX, F. and BERTHELIN, J. Organo-mineral complexes in relation to pedogenesis. In *Interaction of Soil Minerals with Natural Organics and Microbes.* SSSA Special Publication No. 17. Madison, SSSA, 1986, 549-592.
This paper reviews current knowledge of the occurrence and properties of low molecular weight organic substances in soil which have metal complexing ability, particularly in relation to pedogenic processes.

MACKIE, L.A. and MUNRO, J.M. The effect of cultivation on the soil and on the incidence of powdery scab (*Spongospora subterranea)* on potatoes (*Solanum tuberosum.*) *Aspects Appl. Biol.*, 1986, **13**, 293-300.
The effect of soil cultivation on the soil physical environment, root and top growth, and on the incidence of powdery scab disease *Spongospora subterranea* was studied. Both the paraplough and the shakaerator treatments improved physical properties of the soil and allowed deeper root growth than in the soil treated with a tine cultivator. Total nitrogen uptake by the crop was also higher on the paraplough and shakaerator treated soils. Tubers from the shakaerator treated soil had a significantly higher incidence of powdery scab. The subsoil of the

shakaerator treated soil was wetter at high potentials (-1 kPa) than the paraplough treated soil, but not wetter than the tine cultivated soil.

McPHAIL, R.I., ROMANS, J.C.C. and ROBERTSON, L. The application of micromorphology to the understanding of Holocene soil development in the British Isles: with special reference to early cultivation. *Proc. Int. Working Meeting Soil Micromorph., 7th, Paris, 1985.*
In this account the history of Holocene soil development throughout the British Isles is reviewed from the literature and from the micromorphological work of the authors, with special reference to material derived from archaeological sites throughout the United Kingdom.

1423 MELLOR, A. Hydrobiotite formation in some Norwegian arctic-alpine soils developing in Neoglacial till (note). *Norsk. Geol. Tidsskr.*, 1986, **66**, 183-185.
In two podzolised soil profiles developed in an arctic-alpine locality of southern Norway, weathering of mica has led to the formation of hydrobiotite after only 230 years of soil development. The rapid formation of hydrobiotite in these profiles indicates that chemical weathering is significant even in arctic-alpine environments and should be given more emphasis, especially in modelling studies, than has occurred previously.

1419 MELLOR, A. Textural and scanning electron microscope observations of some arctic-alpine soils developed in Weichselian and neoglacial till deposits in Southern Norway. *Arctic and Alpine Res.*, 1986, **18**, 327-336.
Particle size data are supplemented with SEM observations in an attempt to investigate both the nature and origin of some Norwegian till deposits, and the subsequent processes of soil development occuring within them. Comparisons are made between 9000-year old terrain, which has been exposed throughout post-glacial time, and terrain vacated by Neoglacial glacier advances about 230 years ago. Furthermore, comparisons are made between two low altitude, maritime and geologically acidic sites, and two high altitude, continental and geologically basic sites. Textural differences between the tills are considered to result from variations in both the length of time over which they were deposited and the bedrock from which they were derived. Processes of soil development are more advanced in the older profiles, and in those developed in the more environmentally favourable low altitude locations.

MILLARD, P. and MacKERRON, D.K.L. The effects of nitrogen application on growth and nitrogen distribution within the potato canopy. *Ann. Appl. Biol.*, 1986, **109**, 427-437.
The effect of applying nitrogen (N) fertiliser on the growth and distribution of N within the potato canopy was studied in 1983 and 1984. In both years N was applied either in excess of that required to produce maximum tuber yields, or not at all. The large application of N changed the pattern of canopy growth — stimulating growth of leaves at the top of the stem, particularly lateral branches, for longer during the season, and accelerating the death of (shaded) leaves at the base of the canopy. The pattern of canopy senescence was, therefore, changed from a synchronous to a progressive type. Application of nitrogen fertiliser at supra-optimal rates increased the N contents of leaves, stems and tubers. The extra N in the leaves of these plants was present as reduced N in all leaf positions, and as nitrate (NO_3) in the lowermost leaves. In addition, substantial quantities of NO_3^- were also stored in the stems. Part of this extra N in the canopy was redistributed during subsequent growth, especially to the lateral branches as crop N uptake slowed towards the end of the season. In addition, substantial quantaties of N were also potentially available for redistribution to the growing tubers. There was little redistribution of N-deficient plants. It is suggested that redistribution of N in the canopy of N-replete plants allowed the growth of lateral branches towards the end of the season, thereby maintaining photosynthetically active leaves for longer than N-deficient plants.

1401 MILLARD, P. The nitrogen content of potato (Solanum tuberosum L) tubers in relation to nitrogen application — the effect on amino acid composition and yields. *J. Sci. Fd. Agric.*, 1986, **37**, 107-114.

Nitrogen application increased the yield and nitrogen content of potato tubers, while having little effect upon the proportions recovered as amides or the different amino acids. The yields of nutritionally essential amino acids were therefore substantially increased to a maximum of 256, 308 and 384 kg ha^{-1}, at the highest rate of nitrogen application (250kg N ha^{-1}), in three experiments. These yields were significantly higher than those found with the nitrogen application rate optimal for tuber dry matter production (213, 195 and 331 kg ha^{-1}, respectively) in the same experiments. Because the amounts of each essential amino acid contained in a unit weight of fresh tuber increased with nitrogen supply, application of more fertiliser than is needed for maximal tuber dry matter production increased protein yields without decreasing the nutritional quality.

MILLARD, P. and MACKIE, L.A. The influence of nitrogen supply on potato yield and quality. *MISR Technical Note No. 8* Aberdeen, Macaulay Institute for Soil Research, 1986.

1421 MILLARD, P. and MARSHALL, B. Growth nitrogen uptake and partitioning within the potato (solanum tuberosum L.) crop, in relation to nitrogen uptake. *J. Agric. Sci.*, 1986, **107**, 421-429.
The potato crop can take up more nitrogen than it needs to satisfy immediate requirements for growth. This extra nitrogen appears predominantly in the foliage as soluble protein and nitrate in the leaves, and nitrate in the stems. Reduced nitrogen in the tubers becomes a large component of this extra nitrogen during tuber bulking. The effect of nitrogen uptake on tuber yields was studied by considering tuber growth to be a consequence of four processes. These are: radiation interception, conversion of intercepted radiation to dry matter, partitioning of dry matter between tubers and the rest of the plant and regulation of tuber dry matter contents. Maximum tuber yields of final harvest were achieved by applying 150 kg N/ha. Yield increases were due to increased radiation interception, while the photosynthetic efficiency of the canopy and the dry matter contents of the tubers were little affected.

1388 MILLARD, P., SHARP, G.S. and SCOTT, N.M. The effect of sulphur deficiency on the uptake and incorporation of nitrogen in ryegrass. *J. Agric. Sci.*, 1985, **105**, 501-504.
Sulphur deficiency reduces the yield and sulphur content of ryegrass at the fourth cut. The distribution of the forms of nitrogen is also altered, with a decrease in the levels of the sulphur containing amino acids cysteine and methionine, as well as arginine, histidine, lysine, glycine, leucine, serine and threonine, and as an increase in the level of asparagine. Sulphur deficiency, therefore, decreases the quality of the protein found in grass, as well as reducing the yield.

MILLER, H.G., ALEXANDER, C.E., COOPER, J., KEENLEYSIDE, J., McKAY, H., MILLER, J.D. and WILLIAMS, B.L. Maintenance and enhancement of forest productivity through manipulation of the nitrogen cycle. Final Report to the European Research and Development Programme; Wood as a renewable raw material. Contract No. BOS-093 UK.

MORRIS, R.J.F. and SHIPLEY, B.M. Drainage guidelines for the soils of Scotland. *Soil Use Manage.*, 1986, **2**, 109-114.
A set of guidelines has been produced to indicate the range of drainage problems to be encountered under Scottish conditions, along with some of the main factors to be considered in the design philosophy for the treatment of these problems. The identified categories are briefly discussed, together with the potential application of the guidelines.

1390 NADEAU, P.H. The physical dimensions of fundamental clay particles. *Clay Miner.*, 1985, **20**, 499-514.
Quantitative transmission electron microscope techniques are demonstrated for the investigation of smectites and interstratified clays. The results provide new insights into the nature of these materials and explain their large surface areas in terms of the dimensions of dispersed clay particles. Relationships between their structure as examined by X-ray diffraction and the distribution of particle types within the clay are also developed. The methods of crystal growth of these

particles are evaluated from relationships between particle volume and area, length and thickness. The results may be applicable to the behaviour of these materials in soils and sediments, as well as in laboratory systems.

1420 NADEAU, P.H. and BAIN, D.C. Composition of some smectites and diagenetic illitic clays and implications for their origin. *Clays Clay Miner.*, 1985, **34**, 455-464.
Chemical analyses of illitic and smectitic clays have been performed by X-ray fluorescence spectroscopy in order to determine the potassium content, structural formulae and cation exchange capacity. These results are evaluated in conjunction with X-ray diffraction and quantitative transmission electron microscopy data and characterize in detail the chemical nature of these clays which are important soil mineral constituents.

NISBET, T.R. Changes in the chemistry of water passing over and through soils in forested and unforested sites at Loch Fleet, Galloway. In: *The Loch Fleet Project — a report of the pre-intervention phase (1) 1984-86*. Edited by G. Howells. Leatherhead, CEGB, 1986, A5-5.5.

NOLAN, A.J. Report of percolation tests carried out at Muirhead, Muir of Fowlis, Alford. (Restricted circulation).

NOLAN, A.J. The Soils and Land Capability Classification of the proposed route of the dual carriageway extension south of Stonehaven. (Restricted circulation).

1407 PATERSON, E., BUNCH, J.L. and DUTHIE, D.M.L. Preparation of randomly-oriented samples for X-Ray diffractometry. *Clay Minerals*, 1986, **21**, 101-106.
A new method of preparing randomly-oriented clay samples for X-Ray diffractometry is proposed, involving evaporation of an acetone suspension of a freeze-dried clay on a glass slide. Using this method an XRD trace may be obtained using 10-15mg sample as opposed to the 100-200mg of sample required by conventional methods.

PEAT AND FOREST SOILS DEPARTMENT. Survey and assessment of peat resources at Springfield, Whim and Auchencorth Mosses, near Penicuik, Midlothian. A Report for Scottish Agricultural Industries.

PEAT AND FOREST SOILS DEPARTMENT. The peatlands of the Shetland Isles. Digital Map. Scale 1:175 000. Aberdeen, Macaulay Institute for Soil Research, 1986. Available on request.

PEAT AND FOREST SOIL DEPARTMENT. The peat resources of Castlehill, Isle of Islay. A Report for the Scottish Development Department.

PROE, M.F. Predicting the effects of whole-tree harvesting on long-term site productivity for stands of Corsican pine. *Proc. IEA Workshop 'Predicting consequences of intensive forest harvesting on long-term productivity, Sweden, 1986*, 117-129.
Simulation models are useful tools for synthesising information from a large number of sources. One such model, FENDS, has been described and used to predict the long-term consequences of whole-tree harvesting on site productivity. It is concluded that, where possible, fertilisers would be best used to improve growth in conventionally harvested systems rather than to support intensive harvesting practices.

RITZ, K. and ROBINSON, D. Carbon and nitrogen in the soil microbial biomass associated with a spring barley crop. *Int. Congress Microbiol., 14th, Manchester, 1986*. Abstract P.G8-11, 284.

ROBERTSON, J.S. Levenshope Rig – soil and land capability assessment. (Restricted circulation).

ROBERTSON, L. Multi-area measurement from maps and soil thin sections using a microcomputer and graphics tablet. In *Microcomputer Applications in Geology*. Edited by J.T. Hanley and D.F. Merriam. London, Pergamon Press, 1986, 237-255.

Area measurement of two dimensional irregular shapes may be carried out using an Apple Microcomputer and Graphics Tablet. Additional software, and modification to the manufacturer's supplied software is listed, to enable multi-area measurement and analyses on a percentage area basis to be carried out on source documents, such as simple soil maps or photomicrographs. Hardware modifications in the form of a flat-bed cursor with illuminated disc greatly improves the ease with which measurements may be made, and permits micromorphological area measurements to be carried out on soil thin sections while simultaneously viewing the microscope image. The accuracy and efficiency of the method is evaluated by comparison with more traditional area measurement techniques.

SHAND, C.A., AGGETT, P.J. and URE, A.M. The spark-source mass spectrometric determination of the trace element composition of human foetal livers. *Proc. Int. Symp. Trace Metabolism in Man and Animals, 5th, Aberdeen, 1984.* Slough, CAB, 1985, 642-645.
The application of spark-source mass spectrometry to the comprehensive, multi-element determination of the trace element composition of human foetal livers is discussed. Data for 30 elements are presented and compared with those for livers from adults, and where available, with published data for human foetal livers.

SHARP, B.L., BARNETT, N.W., BURRIDGE, J.C. and OTTAWAY, J.M. Atomic spectrometry update-atomization and excitation. *J. Anal At. Spectr.*, 1986, **1**, 121R.

SINCLAIR, A.H. and EDWARDS, A. Soil acidity and its interaction with phosphorus and micronutrients. *MISR Technical Note No. 7* Aberdeen, Macaulay Institute for Soil Research, 1985.

SINCLAIR, A.H., ROBINSON, D. and LINEHAN, D.J. Mineral washout from the wet — true or false. *Norgrass*, 1986, No. 26.
Soil analyses throughout the year showed that the prolonged wet weather during the summer of 1985 did not cause serious loss of lime and nutrients.

*SOIL SURVEY STAFF. Soil map of Scotland. Scale 1:630 360. Sheet 30 (Glasgow). £3.00 + Post and packing. (Flat) £1.20; (Folded) 50p.

SPARLING, G.P. and WILLIAMS, B.L. Microbial biomass in organic soils: estimation of biomass C, and the effect of glucose or cellulose amendments on the amounts of N and P released by fumigation. *Soil Biol. Biochem.*, 1986, **18**, 507-513.
The soil microbial biomass can constitute a considerable pool of potentially available plant nutrients and its size and turnover are therefore important factors in the fertility of upland soils receiving low fertilizer inputs. Measurements of the microbial biomass of a heathland soil and larch and pine humus were obtained using microscopic and biochemical methods, and the amounts of N and P in the biomass estimated from the amounts of these elements released from the organisms following chloroform fumigation. The biomass is increased by additions of available carbon substrate to the soils, but anomalously, there is no concomitant increase in the amounts of N and P released from fumigated organisms.

TIPPKOTTER, R., RITZ, K. and DARBYSHIRE, J.F. The preparation of soil thin sections for biological studies. *J. Soil Sci.*, 1986, **37**, 681-690.
The technique of preparing thin sections of soil embedded in polyester resin has been used routinely by mineralogists, but it has been relatively neglected by soil microbiologists. Using the procedure described in this paper, it is now possible to study microbial interactions in soil near plant roots more effectively. The major improvements in the soil thin section technique are the use of a fixative and the gradual dehydration of the soil with a series of acetone: water mixtures of increasing concentration of acetone before infiltrating the soil with resin.

TOWERS, W. and SINCLAIR, A.H. The soils of Caithness. *MISR Technical Report No. 4.* Aberdeen, Macaulay Institute for Soil Research, 1986. £1.00.

URE, A.M. Soil data in the assessment of geochemical and environmental influences on trace element supply. *Proc. Int. Symp. Trace Element Metabolism in Man and Animals, 5th, Aberdeen, 1984.* Slough, CAB, 906-909.
The various types of soil analysis and their role in the assessment of geochemical and environmental influences in trace element supply to animals and Man are briefly reviewed. The capabilities and limitations of soil analysis in predicting and diagnosing anomalies in trace element supply or in relating animal and human disorders to local geochemical or environmental conditions are assessed.

VAUGHAN, D. Effect of humic substances on metabolic processes in plants. *Proc. Symp. Contribution of Humic Substances to the Soil and their Action on Plant Growth, Milan, 1986*, 54-77.
This brief review article emphasizes that, once in solution, humic substances, particularly humic acid, can have a direct and selective effect on plant metabolism and hence growth. These effects depend on the chemistry of the humic substance, the biochemical processes under investigation and the plant species, and can occur in the absence of micro-organisms. Whether such observations can always be extrapolated to field conditions remains an open question particularly as the soil solution contains only small amounts of humic substances which closely resemble the less metabolically-effective fulvic acid.

1405 WEST, T.S. Scotland's land and soils. *Proc. R. Soc. Edinb.*, 1986, **87B**, 125-138.

WHEATLEY, R.E. and CHESHIRE, M.V. A natural direct effect of micro-organisms on soil structure development. *Int. Congress Microbiol., 14th, Manchester, 1986.* Abstract P.B28-3, 130.

WHEATLEY, R.E. and WILLIAMS, B.L. Rates of denitrification in reseeded blanket bog peat. *Int. Congress Microbiol., 14th, Manchester, 1986.* Abstract P.G8-12, 284.

1412 WILSON, M.J. Mineral weathering processes in podzolic soils on granitic materials and their implications for surface water acidification. *J. Geol. Soc.*, 1986, **143**, 691-697.
Many areas where concern has arisen regarding the recent acidification of their surface waters are areas of podzolic soils developed upon granitic parent material. This paper reviews the mineral weathering processes in these soils and the ways in which such processes could be altered by acid deposition are considered.

1410 WILSON, M.J. and BAIN, D.C. Spheniscidite, a new phosphate mineral from Elephant Island British Antarctic Territory. *Miner. Mag.*, 1986, **50**, 291-3.
Spheniscidite is a new phosphate mineral occurring in a soil profile in an area of nesting penguins on Elephant Island. It is the NH_4 dominant analogue of leucophosphite and has the formula $(NH_4,K)(Fe^{3+}, Al)_2(PO_4)_2(OH).2H_2O$. It is monoclinic, $P2_1/n$ with unit cell parameters close to $a = 9.73$, $b = 9.60$, $c = 9.69$A, $P = 102° 16$. The strongest X-ray lines are 6.79 (100), 5.99 (90), 3.05 (45), 7.62 (40)A. Spheniscidite is thought to have formed by the interaction of ammonium phosphate solutions from penguin guano with micaceous and chloritic minerals in the soil. The name is for Sphenisciformes, the order name for penguins, and has been accepted by the IMA Commission on New Minerals and Mineral Names.

WILSON, M.J. and JONES, D. Biological weathering of minerals. *Proc. Meeting Soc. Int. Ital. Sci. Suolo/AIPEA (Italian Group.), Stresa, 1985.*, 57-65.
The weathering of minerals by lichens is illustrated with respect to the decomposition of basalt, serpentinite, granite and other rock types and the relationship to weathering reactions and soil formation in podzolic soils is discussed.

WOOD, S. and GRIFFITHS, B.S. Endosymbionts associated with the hepatopancreas of the terrestrial isopods *Oniscus asellus* and *Porcellio scaber*. *Int. Congress Microbiol., 14th, Manchester, 1986.* Abstract P.G2-27, 234.

WOOD, S., DAVIDSON, M.S. and RUSSELL, J.D. The decomposition of the exoskeleton of the terrestrial isopod *Oniscus asellus* and the microbial deposition

of calcite in soil. *Int. Congress Microbiol., 14th, Manchester, 1986.* Abstract P.G2-26, 234.

1395 WRIGHT, G.G. Some observations of the effect of wind turbulence on the infrared/red ratio. *Int. J. Remote Sensing*, 1986, **7**, 173-178.
A problem in using radiometric data for vegetation studies is that most vegetation canopies are non-lambertian reflectors and view angle can influence spectral response. Results are presented which indicate that wind turbulence has an appreciable effect on the spectral response of a crop and any derived indicators of vegetative vigour. In some studies it may not be sufficient to consider the plant position as constant during measurement.

1413 WRIGHT, G.G. and BIRNIE, R.V. Detection of surface soil variation using high resolution satellite data: results from the U.K. SPOT-simulation investigation. *Int. J. Remote Sensing*, 1986, **7**, 757-766.
A problem in using multispectral (MSS) data for soil and land-system analysis in north-west Europe is the poor spatial resolution. This is insufficient to provide adequate within-field data. The SPOT satellite system will provide MSS data at '20' metres resolution and panchromatic data at '10' metres resolution. For any given ground feature the SPOT MSS mode will provide considerably more sample areas than LANDSAT '80' metre data. The object of this study is to determine how far variation in surface soil parameters can be detected and quantified on the basis of SPOT data.

AGRICULTURAL AND FOOD RESEARCH INSTITUTES IN GREAT BRITAIN

The research programmes of the following agricultural research institutes supported by public funds are co-ordinated by the Agricultural and Food Research Council. These Institutes generally publish annual reports or periodical reports summarizing the research work that is in progress. Full details can be obtained from the Secretaries concerned.

AFRC INSTITUTES

AFRC INSTITUTE FOR ANIMAL DISEASE RESEARCH.
Compton Laboratory, nr. Newbury, Berkshire, RG16 ONN.
Houghton Laboratory, Huntingdon, Cambridgeshire, PE17 2DA.
Pirbright Laboratory, Woking, Surrey, GU24 ONF.

AFRC INSTITUTE FOR ANIMAL PHYSIOLOGY AND GENETICS RESEARCH.
Cambridge Research Station, Babraham, Cambridge, CB2 4AT.
Edinburgh Research Station, Roslin, Midlothian, EH25 9PS.
Edinburgh Research Station, King's Buildings, West Mains Road, Edinburgh, EH9 3JQ.

AFRC INSTITUTE OF ARABLE CROPS RESEARCH.
Long Ashton Research Station, Bristol, BS18 9AF.
Rothamsted Experimental Station, Harpenden, Herts, AL5 2JQ.

AFRC INSTITUTE OF ENGINEERING RESEARCH.
Wrest Park, Silsoe, Bedford, MK45 4HS.

VS**AFRC INSTITUTE OF FOOD RESEARCH.**
Bristol Laboratory, Langford, Bristol, BS18 7DY.
Norwich Laboratory, Colney Lane, Norwich, NR4 7UA.
Reading Laboratory, Shinfield, Reading, RG2 9AT.

AFRC INSTITUTE FOR GRASSLAND AND ANIMAL PRODUCTION.
Welsh Plant Breeding Station, Plas Gogerddan, Aberystwyth, Dyfed, SY23 3EB.
Hurley Station, Maidenhead, Berkshire, SL6 5LR.

AFRC INSTITUTE FOR HORTICULTURAL RESEARCH.
East Malling, Maidstone, Kent, ME19 6BJ.
Hop Department, Wye College, Ashford, Kent, TN25 5AH.
Littlehampton, Worthing Road, Littlehampton, West Sussex, BN17 6LP.
Wellesbourne, Warwick, CV35 9EF.

John Innes Institute, Colney Lane, Norwich, NR4 7UH.

Plant Breeding Institute, Maris Lane, Trumpington, Cambridge, CB2 2LQ.

SCOTTISH AGRICULTURAL RESEARCH INSTITUTES.

Hannah Research Institute, Ayr, KA6 5HL.

Hill Farming Research Organisation, Bush Estate, Penicuik, Midlothian, EH26 OPY.

Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen, AB9 2QJ.

Moredun Research Institute, 408 Gilmerton Road, Edinburgh, EH17 7JH.

Rowett Research Institute, Greenburn Road, Bucksburn, Aberdeen, AB2 9SB.

Scottish Crop Research Institute, Invergowrie, Dundee, DD2 5DA
and
Pentlandfield, Roslin, Midlothian, EH25 9RF.

Scottish Institute for Agricultural Engineering, Bush Estate, Penicuik, Midlothian, EH26 OPH. Roslin, Midlothian, EH25 9RF.

Printed by Avon Litho Limited, Masons Road, Stratford-upon-Avon