Mr. M.S. Davidson

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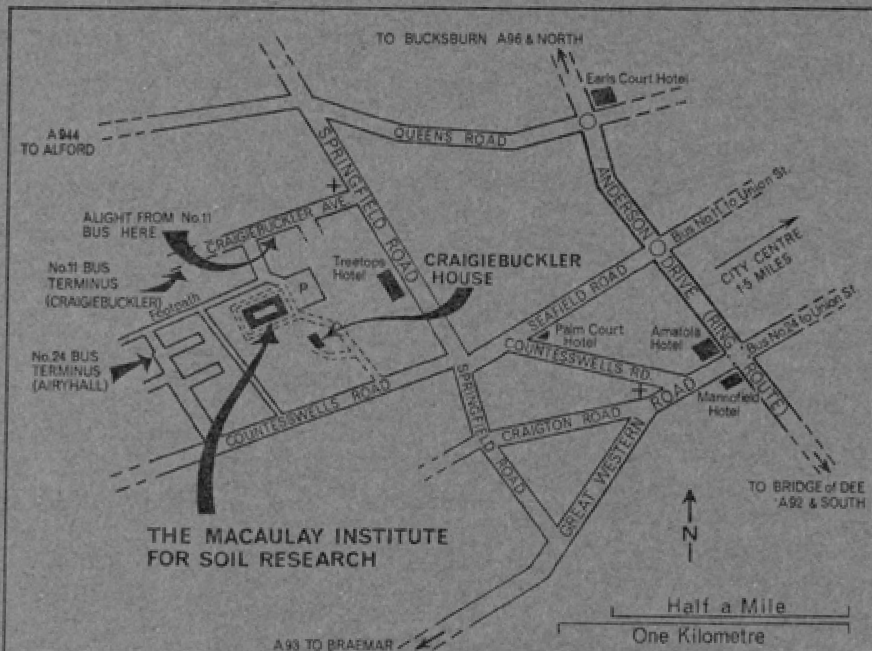

The Macaulay Institute is situated on the western outskirts of Aberdeen, about three miles from the centre of the city. The main entrance is on Countesswells Road, but visitors using public transport should take either the Corporation Bus Route 11 to the point indicated, from which the Institute is reached in a few minutes by Craigiebuckler Drive, or Alexander Northern Scottish Bus Route 24 (less convenient) to the Airyhall (not Braeside) terminus.

Telephone—ABERDEEN (0224) 38611

The main part of this report covers the period from 1st October, 1978, to 30th September, 1979. The staff list is that current in November/December, 1979, and the Introduction is similarly updated. The report was published in May, 1980.

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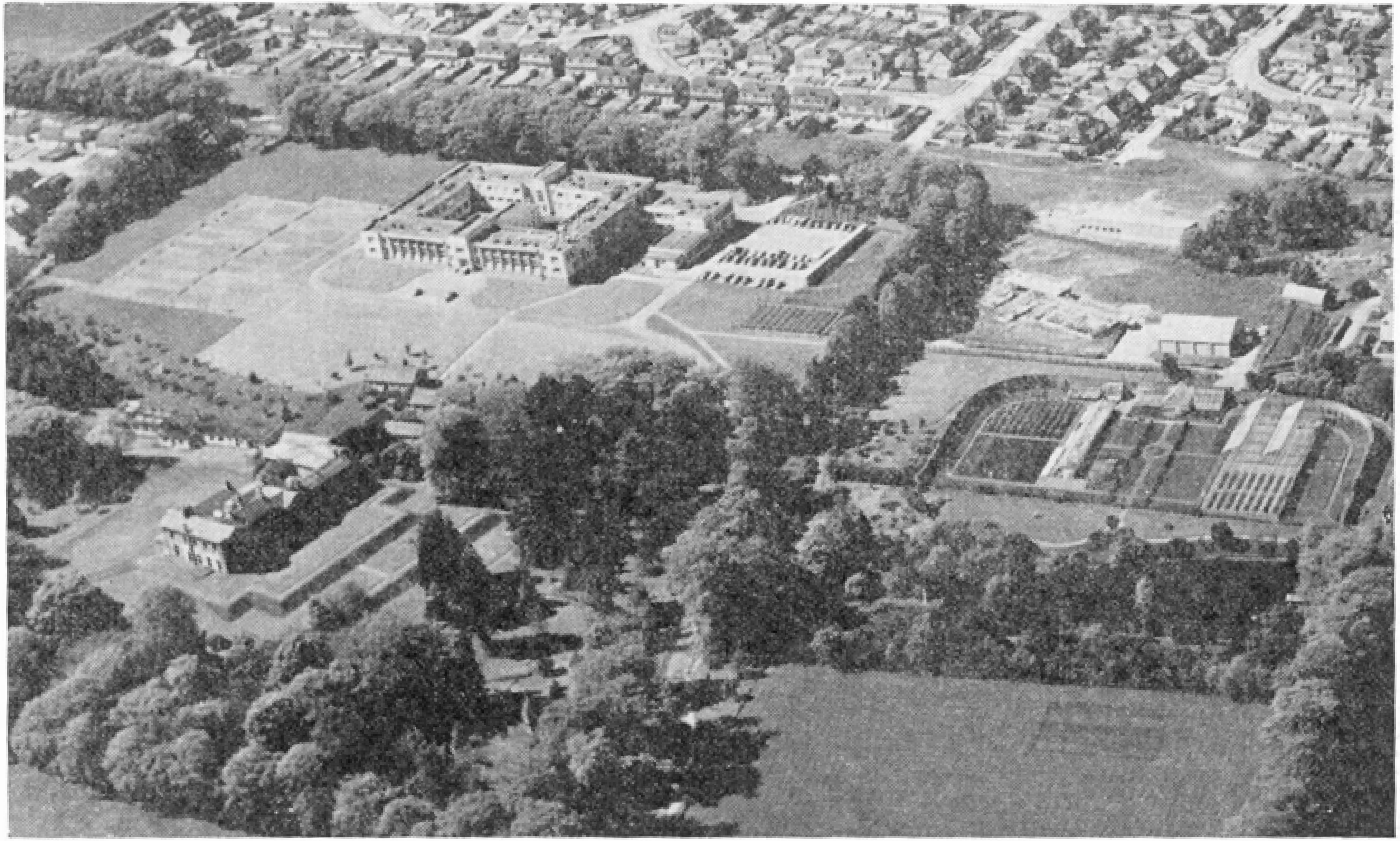
THE MACAULAY INSTITUTE FOR SOIL RESEARCH

CRAIGIEBUCKLER, ABERDEEN

(Founded 1930)



Aerial view of the Macaulay Institute. Craigiebuckler House, the original Institute building and some of its associated outbuildings are in the left-hand foreground with the ornamental pond and the walled garden of the house on the right-hand side. The present main building of the Institute, opened in 1962, is seen surrounded by trees in the upper half of the photograph.

STAFF

1978-79

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

Deputy Director—
E. G. WILLIAMS, B.Sc., Ph.D.

DIVISION OF PEDOLOGY

MINERAL SOILS

Head of Department: R. C. Mackenzie, D.Sc., Ph.D., F.R.S.E.
B. D. Mitchell, B.Sc., C.Chem., F.R.I.C.
M. J. Wilson, B.Sc., Ph.D.
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D. R. Clark.
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Mrs M. Shepherd—resigned 31/1/79.
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Miss L. E. McIntosh—resigned 8/6/79.
Miss Y. Bisset.
Mrs L. R. Brown—resigned 31/3/79.
Miss A. A. Grant.
Miss L. J. Potter.
Miss L. A. Mielewczyk—appointed 11/6/79.
Miss M. I. Thom—appointed 21/5/79.
Miss L. Thomson—appointed 4/6/79.
Mrs C. Buchan—appointed 4/6/79.
D. Johnston.

PEAT AND FOREST SOILS

Head of Department: R. A. Robertson, B.Sc.
S. E. Durno, B.Sc., Ph.D., M.I.Biol.
H. G. Miller, B.Sc.(For.), Ph.D., M.I.For.
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B. L. Williams, B.Sc., Ph.D.
J. D. Miller, L.R.I.C.
A. T. Nicol.
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G. C. Stove, B.Sc., Ph.D.
W. R. Johnston, B.Sc., M.Sc., Ph.D.—appointed 1/10/79 (CEGB Grant).
A. W. Blyth, B.Sc., L.I.Biol.

STAFF—*continued*

J. S. Anderson.
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J. W. Mitchell.
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Miss C. L. Howden.
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Mrs S. J. Leggett (nee Hay)—resigned 21/9/79.
Miss A.-M. Martin—appointed 15/1/79.

SPECTROCHEMISTRY

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I. Black.
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Miss K. M. Duff.
Miss A. E. Horobin—appointed 8/1/79.
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Miss S. Sutherland—appointed 14/5/79.
Miss M. E. Lamont—appointed 21/5/79.
I. M. Still.
E. Lawson.

SOIL ORGANIC CHEMISTRY

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Mrs C. A. Christie.
Miss M. McMaster.
Miss S. Henderson.
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Miss S. E. Noble.

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Mrs M. R. Tyler (nee Moir).
I. Smith.
I. D. McFarlane.
Mrs L. Burns—resigned 5/7/79.

MICROBIOLOGY

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M. S. Davidson.
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Miss C. H. Ogonowski, B.Sc.
Mrs H. A. Kidd.
Mrs R. H. Easton—resigned 2/10/79.
Miss J. A. Russell.
Mrs M. M. Justice.

SOIL FERTILITY

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B. W. Bache, M.A., Ph.D., C.Chem., F.R.I.C.
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N. M. Scott, Ph.D., C.Chem., F.R.I.C.
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K. S. Caldwell, S.D.A., S.D.D.H.
H. Shepherd, L.R.I.C.
G. D. Buchan, B.Sc., M.Sc., Ph.D., M.Inst.P.
J. A. M. Ross, N.D.A.
G. S. Sharp, L.R.I.C.
Miss S. M. Law.
A. H. Sinclair, B.Sc., Ph.D.
T. E. Edmonds, B.Sc., M.Sc., Ph.D., C.Chem., M.R.I.C.
J. Munro.
S. Cooke, B.Sc., Ph.D.—appointed 26/3/79.
Miss C. Ireland.
Mrs H. R. Booth.
C. A. Frost, B.Sc.
Mrs G. Coutts.
Miss E. A. Mackay—resigned 17/8/79.
Mrs R. G. McPherson—resigned 30/9/79.
Miss E. J. Donald.
Mrs A. Shields—resigned 13/6/79.
S. D. Porter.
Mrs C. A. Morice.
Mrs V. J. Hay—resigned 14/9/79.
Miss A. S. Doig.
Miss M. E. Watson.
Miss M. A. McDonald—resigned 17/8/79.
Miss B. Ross.
Miss I. R. McRobbie—resigned 31/12/78.
Mrs E. B. Still—appointed 11/12/78.
Miss S. M. Flett—appointed 5/3/79.
A. G. Gall.
A. R. Douglas.
J. S. Morrison.
J. A. M. Anderson.
W. J. Duncan.

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.
G. J. M. Stephen, B.Sc.—resigned 5/8/79.
D. A. P. McKay, M.A.—appointed 1/8/79.
Mrs S. I. D. Grieve.
Miss E. I. Duff, B.Sc.
Miss M. McDonald—appointed 1/12/79.
Miss A. McDonald.
Miss J. E. Taylor—resigned 31/12/78.
Miss A. Hitz—resigned 20/7/79.
Miss J. A. Sleigh—appointed 26/2/79.

SOIL SURVEY

Head of Department: R. Grant, M.A., B.Sc.
J. W. Muir, B.Sc.(Agr.), M.R.I.C., C.Chem., N.D.A., N.D.D.
E. L. Birse, B.Sc.
J. C. C. Romans, B.Sc.
D. Laing, B.Sc., C.Chem., M.R.I.C.
J. M. Ragg, B.Sc.—resigned 31/3/79.
C. J. Bown, B.Sc.
B. M. Shipley, B.Sc.
A. D. Walker, B.Sc.
D. W. Futty, B.Sc.
J. S. Bibby, 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.
N. A. Duncan, B.Sc.—resigned 16/2/79.
G. Hudson, B.Sc.
C. G. B. Campbell, B.Sc.
D. J. Henderson, B.Sc.
G. G. Wright, B.Sc.
W. Towers, B.Sc.
J. S. Bell, B.Sc.
J. A. Hipkin, B.Sc.
T. W. M. Brown, B.Sc.—appointed 1/1/79.
J. Corbett, B.Sc.—appointed 1/1/79.
A. J. Nolan, B.Sc.—appointed 23/4/79.
W. S. Shirreffs.
A. D. Moir.
Mrs R. M. J. Fulton.
Miss G. Love—resigned 16/2/79.
Miss S. Patterson—resigned 6/4/79.
Miss P. R. Carnegie.
Miss P. M. Sherriffs—11/6/79-30/9/79.
C. Halliday.

LIBRARY AND INFORMATION SERVICES

Librarian Mrs A. H. W. Dickie, A.L.A.
Mrs L. Garden—resigned 6/4/79.
Mrs S. Watt—resigned 31/8/79.
Mrs A. Morrice—25/9/79-11/12/79.
Information Officer Miss E. M. Watson, B.Sc.

TECHNICAL SERVICES

Head of Section A. W. Stuart.
J. H. Normington.
G. J. Gaskin.
A. I. A. Wilson.
J. A. MacDonald.
R. A. Burns—resigned 31/5/79.
N. P. Hird—appointed 6/8/79.

	R. D. Malcolm.
	G. Sim.
	D. W. Clark.
Photographer	J. Mitchell, A.I.I.P., A.I.M.B.I.
	D. J. Riley.
Clerk of Works	G. Forbes.

ADMINISTRATION

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	Miss E. J. Cockburn.
Cashier	Miss H. T. G. Donaldson.
	Mrs M. Milne.
	Miss K. E. Weir, M.A.
Personal Secretary to Director	Miss M. H. F. B. Nicol.
Office Staff	Mrs P. Laing.
	Miss R. Munro—resigned 31/5/79.
	Miss L. S. Thomson—appointed 25/6/79.
	Miss C. A. Duguid—resigned 22/6/79.
	Miss J. Whittaker—8/1/79-22/6/79.
	Miss K. A. Kemp—appointed 21/6/79.
	Mrs I. M. Shand.
	Mrs C. T. Garden.
	Miss L. M. Melvin—resigned 2/2/79.
	Mrs V. A. D. Anderson—19/3/79-9/11/79.
	Miss K. E. Cardno—25/6/79-18/7/79.
	Miss L. B. Coutts—appointed 20/8/79.
Telephonist	Mrs P. M. McSporran.
Storekeeper	A. S. Riddoch.
	Miss E. M. Middleton.
Driver Handyman	I. Findlay.
Attendant	J. D. C. Nicol.
Outdoor Staff	A. Mutch.
	H. Shaw—retired 31/5/79.
	W. L. W. Ross.
	R. A. R. Clarke.
	J. S. West.
	C. S. Robertson—appointed 13/8/79.

HONORARY FELLOWS

Sir W. G. Ogg, M.A., B.Sc.(Agr), Ph.D.(Cantab), LL.D., F.R.S.E. (deceased 25/9/79).
Dr A. B. Stewart, C.B.E., M.A., B.Sc., Ph.D., LL.D., C.Chem., F.R.I.C., F.R.S.E.
Dr R. L. Mitchell, B.Sc., Ph.D., C.Chem., F.R.I.C., F.R.S.E.

VISITING RESEARCH WORKERS

*S. Cooke, Department of Soil Fertility, M.O.D. Research Student.

*Miss E. B.-I. Glass, Department of Soil Fertility, M.O.D. Research Student.

*M. J. Hepher, Department of Soil Fertility, A.R.C. Research Student.

*Miss J. Khalighie, Department of Spectrochemistry, Research Student.

*D. A. P. Mackay, Department of Statistics, A.R.C. Research Student.

*Lau, Chau Ming, Department of Spectrochmistry, Research Student.

Dr R. Martens (Institut für Bodenbiologie, Braunschweig, Federal Republic of Germany).

Mrs J. Martens (Institut für Bodenbiologie, Braunschweig, Federal Republic of Germany).

*A. R. Morrisson, Department of Spectrochemistry, A.R.C. Research Student.

Dr Valerie Orchard (DSIR Soil Bureau, Lower Hutt, New Zealand).

Professor W. F. Pickering (University of Newcastle, New South Wales, Australia).

Pu, Guo-Gang (University of Hofei, People's Republic of China).

*B. Thornton, Department of Plant Physiology, A.R.C. Research Student.

*D. I. Welch, Department of Soil Organic Chemistry, A.R.C. Research Student.

*Mrs K. Welch, Department of Spectrochemistry, Chemical Society Research Student.

*Miss S. G. Williams, Department of Plant Physiology, A.R.C. Research Student.

*P. Wilson, Department of Spectrochemistry, A.R.C. Research Student.

*S. D. Young, Department of Soil Fertility, A.R.C. Research Student.

*Ph.D. Student.

CONTENTS

INTRODUCTION

T. S. West

Some slight changes have been made in the format of this year's Report. The most obvious of these is that the papers cited in the account of each Department's work are listed at the end of the Departmental entry and that the references are numbered sequentially within each entry, irrespective of whether the paper referred to has been published, accepted for publication or submitted to a journal. Thus, each Departmental section acts as a complete record of its work for the year. All of the papers published during the year are listed at the end of the Report alphabetically under the name of the first-mentioned author and there is, as before, a short summary of the contents of the paper and a note of its number on the Institute's publications list. It should be noted that reprints of some publications are not available for distribution and we have had to restrict the numbers of others because of escalating costs. In general with most other similarly placed research stations, we have now decided to discontinue the binding and distribution of collections of Institute reprints.

Another change that will be seen immediately is that there are now nine Departments of the Institute. The former sections of the Department of Pedology have become the Departments of " Mineral Soils " and " Peat and Forest Soils." They are still, however, closely associated within the Division of Pedology. The change was instituted on 1st July. Dr R. C. Mackenzie has organisational responsibility for the Division and is Head of " Mineral Soils " with Mr B. D. Mitchell as Deputy Head and Mr R. A. Robertson as Head of " Peat and Forest Soils."

As on previous occasions I am happy to report that the Institute has continued to make substantial progress in its programmes during the past year. The number of papers published during the year has increased to 117 and there are approximately the same number submitted or accepted for publication. This, of course, is only one index of the success of our efforts though we recognise it as an important one, because most of our research activities are geared to long-term fundamental work which is best disseminated to the scientific community through the publication of original papers in scientific journals, and reviews or progress papers in specialist journals. Our contact with the farming community continues to be indirect and largely through the services we provide to the agricultural advisers of the North of Scotland College of Agriculture, though we naturally have most-welcome informal contacts, in the field literally, with farmers in the case of our Soil and Peat Survey staff engaged in their routine duties, the staff of the Department of Soil Fertility, and to a lesser extent other Departments, engaged on field experiments in various locations. It is perhaps a weakness in the way our work is commissioned that our contacts with the farming community are so indirect and is something that we review from time to time. However, few would dispute that such fundamental long-term work on soil is vitally important for the future of all branches of agriculture. It may well be that, in the long run, fundamental work may have to predominate within the Institutes of the Agricultural Research Service rather than much of the present work which is devoted to producing marginal increases in yields of livestock or crops usually at the expense of increasing intensification or specialisation, and sometimes for the commercial benefit of the few rather than the good of the population of the UK as a whole. The mounting widespread criticism of the Common Agricultural Policy of the European Economic Community in relation to the benefits derived by the " few " at the cost of the " many " may well spill over into the area of research in agriculture. It is interesting to see that such a debate is now beginning to shape the policy of the United States Department of Agriculture in relation to its own funding of research.

During the year, the " crash " hill-land survey mentioned in the previous Report has progressed considerably. Despite difficulties of late snows in early 1979, bad weather and late delivery of vehicles, our staff have now surveyed a total of some 20,000 km² of the estimated 36,000 km² involved—12,000 km² in 1979. As will be seen in the Soil Survey report (Ssection 9) the cartographers are now well poised to produce the necessary maps relating to soils, and agriculture and forestry land use capabilities.

Another particularly interesting feature of this year's Report is the account given by Dr E. G. Williams, Deputy Director of the Institute, of the work of his Department of Soil Fertility. In it he takes stock of the results of several years' work and reviews some interesting trends, particularly in relation to agriculture in the North of Scotland. Amongst the features discussed are the requirements, time of application and placement of fertilisers for various crops, the effects of minimum cultivation methods on barley grown under the conditions that prevail in the North of Scotland, chemical composition of crops, the influence of trace element status on main agricultural crops in relation to (a) different soil series, and (b) animal nutrition, the effects of soil acidity, etc.

The joint study on biological weathering initiated during the year by the Departments of Microbiology and Mineral Soils is also of particular interest. The method of attack of some lichens and fungi on mineral particles in soils and rock surfaces is shown to be due to their production of metabolic products such as oxalic acid. Observations on the use of the acetylene-reduction test in relation to the assessment of nitrogen fixation by soil bacteria associated with cereal roots show that some reservation must be attached to the significance of this widely applied diagnostic criterion. Meanwhile some interesting facts are emerging on the ability of various cereals to obtain nitrogen nutrition from soil bacteria at the soil-root interface, though it is too early to draw any conclusions about their significance. The report of the Department of Soil Organic Chemistry reveals that, under the same conditions, organic compounds in soil can increase the availability to plants of some trace elements and decrease that of others. The effects of different cropping systems on the levels of some of the physiologically active components of organic matter in the soil are now being examined under field conditions. Chemical studies on the nature of humic substances and their origins have shown evidence that carbohydrate-like materials other than polysaccharides may be present in fulvic acid polymers.

During the year, a microprocessor discussion group has been formed within the Institute to examine the impact of the new technology on our scientific instrumentation and research work in general and, of course, to rationalise the acquisition and use of microprocessors in the various Departments. The Department of Statistics has improved its microcomputer facilities by the addition of more memory, a second tape cassette and a printer to its Commodore PET and a similar instrument in the Department of Peat and Forest Soils has also had its capabilities significantly increased. The former Department has planned a number of data bases for trace element work, for data from soil complexes and from LANDSAT. It has also devised new coding forms in conjunction with the Department of Soil Survey for the current hill-land survey.

Interest in the effects on crops and soil of trace metals contained in certain sewage sludges applied to agricultural land as fertilisers has continued to influence the work of the Department of Spectrochemistry, as has the more local problem associated with the copper content of distillery wastes deposited on agricultural land. Work this year has confirmed the continuing plant availability from sludge-treated soils of elements such as copper, nickel and zinc and the unavailability of chromium as before. In conjunction with the Department of Soil Fertility it has been found that there are high levels of extractable copper (*ca.* 300 mg Cu/kg soil) in the surface soil of land treated for *ca.* 70 years with distillery wastes as opposed to normal levels (*ca.* 1-5 mg Cu/kg soil). On such soils, the germination of oats was reduced by *ca.* 90%, but barley, ryegrass, clover, swedes and potatoes grew normally with plant copper levels ranging from 7-26 mg Cu/kg dry matter. On the other hand, a site ploughed and reseeded in 1976 and subjected to intensive grazing gave samples of mixed herbage, ryegrass and clover containing only 11-13 mg Cu/kg.

The age-old problem of crop/soil samples containing insufficiently high levels of trace elements for direct analysis has received attention during the year. An elegant preconcentration technique has been devised which involves cementation of the trace elements from solution on to aluminium powder. This has allowed geochemically important elements such as gold, osmium, palladium, platinum, rhodium and silver to be determined within our instrumental capabilities, as well as facilitating the determination of others of known biological importance such as arsenic, antimony, copper, selenium, tellurium, thallium and tin, but not the transition elements. The procedure is also particularly useful in that the alkali and alkaline earth elements do not occur in the concentrate, thus obviating the interference which they often cause in trace element spectroscopy.

The work on the development of a laser method for the remote-sensing of sulphur dioxide in the atmosphere has progressed to an advanced state and, during the coming year, measurements will be made of the SO_2 concentration in the air above growing plants.

It is now recognized that aluminium in solution in acidic soils is likely to be in the form of a soluble hydroxyaluminium silicate complex, termed proto-imogolite. This complex must play a role in the transport of aluminium from upper to lower horizons, and in its leaching from the soil profile. Under favourable conditions in the soil, the soluble proto-imogolite forms imogolite, a regular tubular aluminium silicate which has been found to be a general constituent of the B horizon of podzols and acid brown forest soils. Synthetic imogolite can be synthesized in the laboratory, and this process is now covered by a patent.

Lastly, in the context of trace elements and spectroscopy, it is worthwhile drawing attention to our new found ability, by means of electron paramagnetic resonance measurements, to follow the chemical changes that occur when certain trace elements such as copper are taken up from solution by wheat roots at the interface and pass up the root into the above-ground parts of the plant. The ability to observe such bioinorganic chemical changes *as they occur* within living plants should, in due course, considerably add to our knowledge of how plants utilize or are adversely affected by deficiencies or excesses of such biosignificant trace elements. The scope of the EPR technique is limited to those of the paramagnetic species that show signals measurable against the background "noise." Fortunately, this is likely to include many of the bioessential elements, and other spectroscopic or electrochemical techniques should facilitate study of the speciation of other elements in due course.

Significant advances will be found in many other areas of this year's Report, *e.g.* in the development of LANDSAT multispectral imagery and aerial photography to provide increasingly refined and detailed information on geomorphology, land-use, vegetational features, etc., to such an extent that it is now possible to differentiate various crops from each other, between cloud cover and snow on terrain in LANDSAT imagery, even to follow features such as heat-loss from land and buildings, phyto-plankton blooms in surface waters, etc. Work on pollen analysis and the production of pollen maps has now reached an advanced stage of refinement and significant progress has been made in studying root-moisture relationships in peat and nutrient uptake from forest soils and from the atmosphere.

New Instrumental Capabilities

Restricted funds for the purchase of capital equipment and the necessity to have a new computer capable of handling our future requirements for soil and other data banks, on-line facilities to sophisticated instruments, digital mapping procedures, etc., has severely restricted the acquisition in 1979 of new capital equipment other than the "Data General" Eclipse C/150 system. The Eclipse has a core memory of 512K bytes with a 50 M byte disk subsystem, diskette and nine-track magnetic tape subsystems. It will be, or is now being, provided with facilities for connecting to other devices such as a paper-tape reader and graph plotter and, of course, various other laboratory instruments. Indeed the only other major equipment item acquired—a Perkin Elmer Model 580B Infra-red spectrometer was purchased with the necessary interface for the Eclipse computer so that the spectroscopists can have direct computer access on the instrument as they use it. The Eclipse System will also provide simultaneous access for a number of years at keyboard/video display terminals in other parts of the Institute and its advanced operating system will give the soft-ware capability of much larger general-purpose computer systems to handle time-storing, batch and "real-time" operations. The optimizing FORTRAN computer will also produce a more efficient code. A high performance liquid chromatograph and a radio-liquid/gas chromatograph to facilitate work on radio-isotope labelled organic material were the only purchases of capital equipment possible in the 1979-80 budget so that many members of staff with aspirations to acquire new equipment, and to replace obsolescent laboratory or farm instruments had to be disappointed. This may, unfortunately, have to be a continuing observation in future years. We are, however, very pleased to acknowledge the donation of a Varian Techtron (Model 65) metal hydride vapour generator by the manufacturers to the Department of Spectrochemistry.

EVENTS AND PEOPLE

Fourth T. B. Macaulay Lecture

The Fourth T. B. Macaulay Lecture, entitled "Whither Soil Research?" was delivered by Dr G. W. Cooke, CBE, FRS, Chief Scientific Officer of the Agricultural Research Council, in the Wedgewood Suite of the Treetops Hotel on 23rd November, 1979, before an audience estimated to be in excess of 200. Dr Cooke's lecture is presented as the Appendix to this report.

It is with great regret that we record the death on 25th September, 1979, of Sir William Gammie Ogg, Founder and first Director of the Institute, a member of the Council of Management and an Honorary Fellow of the Institute. A brief tribute was paid to him for his sagacious and far-sighted guidance of the Institute in its formative years in the 39th issue of the Institute news magazine, Profile. The photograph of Sir William shown here was taken *ca.* 1960.

Professor J. I. G. Cadogan, Forbes Professor of Chemistry at the University of Edinburgh, a DAFS representative on the Council of Management since 1969, has resigned upon taking up his new post of chief scientist at B.P. Research, Sunbury-on-Thames. We are sorry to lose his services, but are also pleased to welcome Professor Lord Tedder, Purdie Professor of Chemistry at the University of St Andrews, to fill the vacancy.

Visitors to the Institute

Dr Ralph Riley, FRS, who succeeded Sir William Henderson, FRS, as Secretary of The Agricultural Research Council, visited the Institute in July. Visits were also received from other members of both ARC and DAFS during the year. Mr R. A. R. McLennan, MP for Caithness and Sutherland, and Junior Minister in the Labour Government, came to the Institute to discuss peat resources and problems associated with peat research in Scotland in March.

Several overseas delegates to the XXII Colloquium Spectroscopicum Internationale and the 8th International Conference on Atomic Spectroscopy which was held in Cambridge during the year, took the opportunity to visit the Institute. They are all well-known in various fields of spectroscopy

Sir William Gammie Ogg, 1891-1979.
First Director, 1930-43.

and included Professor K. Fuwa, Tokyo University, Japan; Dr H. Falk, Academy of Sciences, Berlin, German Democratic Republic; Professor C. L. Chakrabarti, Carleton University, Ottawa, Canada; Professor R. M. Barnes, University of Massachusetts, Amherst, USA; Dr L. R. P. Butler and Mr P. F. S. Jackson, National Physical Research Laboratory, Pretoria, Republic of South Africa and Mr P. Bennett of Varian Techtron Pty., Melbourne, Australia. Professor Chakrabarti lectured on " New directions in atomic absorption spectroscopy," Dr Butler on " The environmental programme of South Africa " and " Metal carbide/graphite tube electrothermal atomization " and Dr Falk on " The theory and application of non-thermal excitation sources." Many other distinguished visitors to the Institute also gave colloquia, *e.g.* Professor A. Hulanicki, University of Warsaw, Poland, on " Some aspects of electroanalytical chemistry in relation to trace metals "; Dr R. L. Willson, Brunel University on " Free radicals in biochemistry "; Dr D. W. Cowling, Grassland Research Institute, on "Atmospheric sulphur and the nutrition of forage plants "; Dr S. C. Jarvis also of G.R.I. on " Some aspects of cadmium in soils and crops "; Professor J. B. Dixon, Texas A & M University, U.S.A., on " Mineralogical research for solving soil problems "; Dr W. E. Larson, University of Minnesota (St Paul), U.S.A., on " Soil and water management "; Professor S. Larsen, Agricultural University of Copenhagen, Denmark, on " Kinetics of phosphate immobilzation in soil "; Dr N. Deans, Robert Gordon's Institute of Technology, Aberdeen, twice, on " Microprocessors—principles and applications " and " The ins and out of computers "; Dr D. J. Painter, Lincoln College, Canterbury, New Zealand, on " The work of the New Zealand Agricultural Engineering Institute, with particular reference to cultivation and soils," and Professor J. K. Syers, Massey University, Palmerston North, New Zealand, on " Cycling of phosphorus and nitrogen by earthworms."

Short term visitors from twenty-four countries came to the Institute during the year and Group visits included parties from the ADAS Land Capability Working Party, postgraduate and honours students from the Universities of Edinburgh, Aberdeen and Wales (Bangor) in soil science, chemistry, biochemistry and geography, The North of Scotland College of Agriculture, pupils of the Aberdeen Schools Science Convention and various local agricultural colleges.

Honours and Appointments

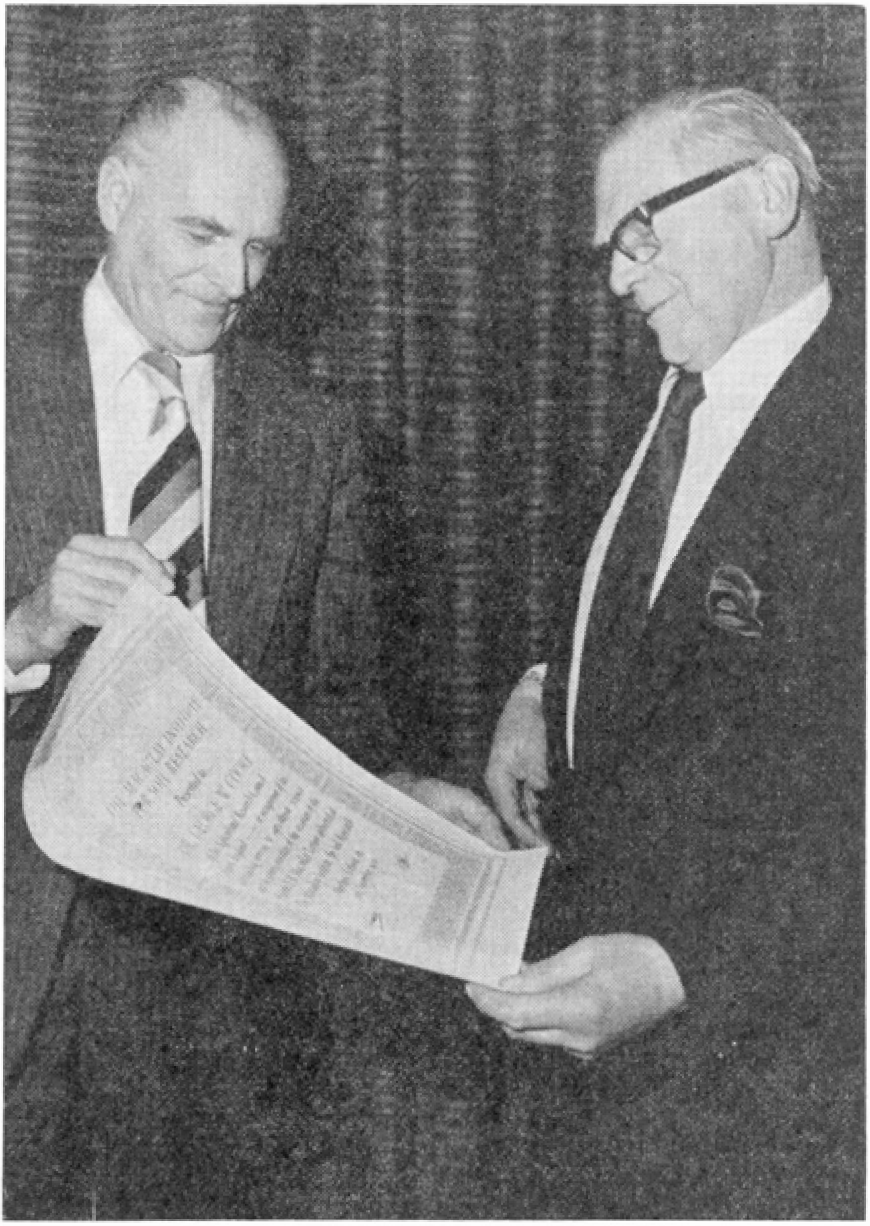
Dr V. C. Farmer and Dr T. S. West were elected to Fellowship of The Royal Society of Edinburgh during the year. Mr M. J. Bracewell was appointed to the Editorial Board of The Journal of Analytical and Applied Pyrolysis; Mr R. A. Robertson was made a member of the Remote Sensing Group Committee of the Natural Environmental Research Council and Dr G. C. Stove was elected to the Council of Management of the U.K. Remote Sensing Society. Dr West was appointed to the Royal Society Study Group on the Nitrogen Cycle, the Science Research Council Working Group on Tertiary Education in the Analytical Sciences and the Joint International Affairs Committee of The Royal Institute of Chemistry and The Chemical Society. Dr A. M. Ure was elected to the Council of The Chemical

Society's Analytical Division and has also been appointed as The Chemical Society representative on the Department of the Environment's Standing Committee of Analysts. Dr M. J. Wilson was elected Secretary of the Clay Minerals Group of the Mineralogical Society and Dr D. C. Bain became the Treasurer of the same Society. Dr H. G. Miller has been appointed as the U.K. representative on an international committee on the effects of sulphur dioxide and its derivatives on natural ecosystems, agriculture and fisheries.

Lectures and Visits Overseas by Institute Staff

Dr T. S. West, Director, presided over the affairs of the Division of Analytical Chemistry of the International Union of Pure and Applied Chemistry at the General Assembly of IUPAC in Davos, Switzerland, in September. He also chaired the Division Presidents' Group and, at the invitation of The Royal Society, served as a U.K. delegate to the Council of IUPAC. In August he served as The Chemical Society representative at the Federation of European Chemical Societies Working Party on Analytical Chemistry meeting in Helsinki. The costs of these visits were paid by IUPAC, The Royal Society and The Chemical Society. Dr B. A. Goodman attended the meetings of the IUPAC Commission on Molecular Structure and Spectroscopy with the award of a Royal Society Wates-IUPAC Bursary at the IUPAC General Assembly in Davos, Switzerland, in September. Dr Goodman also lectured at the NATO advanced Studies Institute, University of Illinois, U.S.A., during a two week period in July, the costs being met by NATO. Dr V. C. Farmer undertook a British Council sponsored visit of CNRS centres in France and Belgium in June as a follow-up to the Centre de Pedologie Biologique (Vandoeuvre) CNRS group visit to the Institute in 1978. Mr R. A. Robertson accepted an invitation to attend the International Peat Society Praesidium Meetings in Hanover for three days in June and subsequently another to attend a Symposium on new technology in the peat industry at Bad Zwischenahn (West Germany). Mr B. D. McPhail, partly funded by a NATO grant, attended a course on magnetic resonance of paramagnetic ions in biological and related systems at the NATO Advanced Studies Institute near Naples for two weeks in June. Dr B. L. Sharp lectured, by invitation, at the EEC Joint Research Laboratories and visited EURATOM at Ispra, Italy, to discuss collaboration in the field of laser remote sensing of trace gases in the atmosphere. Dr R. C. Mackenzie attended and lectured by invitation at the THERMANAL '79 Conference at Stary Smokovec, High Tatras, Czechoslovakia, and the Eighth Conference on Clay Mineralogy and Petrology near Prague in October. Dr Mackenzie's expenses were met by the organizing bodies. Dr P. C. DeKock similarly accepted an invitation to be the principal guest speaker at the UCLA Trace Elements Symposium, Los Angeles, U.S.A. Dr H. A. Anderson and Dr M. V. Cheshire gave invited lectures at an International Colloquium on the migration of organo-mineral compounds in mineral soils at Nancy, France, in September.

The costs of all these visits were paid by the organizing authorities of the meetings concerned.



Presentation of the Scroll of Honour to Dr G. W. Cooke, C.B.E., F.R.S. (right-hand side) by the Director on the occasion of Dr Cooke's delivery of the 1979 T. B. Macaulay lecture "Whither Soil Research?" November, 1979. The lecture is reproduced in the Appendix of the Report.

Other very useful visits were made by staff with funds provided by DAFS as follows: Dr R. O. Scott (Spectrochemistry) attended the meetings of the IUPAC Commission on Spectrochemical and other Optical Procedures for Analysis at the IUPAC General Assembly in Davos, Switzerland, in September. Dr A. M. Ure (Spectrochemistry) visited the Department Scheikunde, University of Antwerp, Belgium, in May and the Symposium on the Analytical-geochemical Methods for Investigation of Geological Materials, Tatranska, Czechoslovakia, in October. Mr J. M. Bracewell (Mineral Soils) attended the Pyroloysis Symposium at the Holderness School, Plymouth, U.S.A., in July. Dr A. E. S. Macklon (Plant Physiology) attended the Fourth International Workshop on Ion Transport in Plants in Toronto, Canada, in July. Dr H. G. Miller (Peat and Forest Soils) attended a Symposium on the Impact of Intensive Harvesting on Forest Nutrient Cycling in Syracuse, New York, U.S.A., in August. Dr J. R. Bacon (Spectrochemistry) attended the Eighth International Mass Spectrometry Conference, Oslo, Norway, in August. Dr B. W. Bache (Soil Fertility) visited research centres in Uppsala, Sweden, and Copenhagen, Denmark, in September. Whilst on this visit Dr Bache also accepted an invitation from the Norwegian Forest Research Institute to discuss problems relating to acid precipitation and to lecture on Soil Acidity and Acidification. He also gave a lecture at the Norwegian Agricultural University. Dr B. A. Goodman (Spectrochemistry) attended the International Conference on Mössbauer Spectroscopy in Portoroz, Yugoslavia, in September; Mr R. A. Robertson and Dr P. D. Hulme (Peat and Forest Soils) attended the International Symposium on Classification of Peat and Peatlands in Helsinki, Finland, in September, and Mr Robertson attended the Meeting of the Council of the International Peat Society. Mr A. H. Knight (Soil Fertility) attended the Tenth Annual Meeting of the European Society for Nuclear Methods in Agriculture (ESNA), Belgrade, Yugoslavia, in October; Dr R. C. Mackenzie (Mineral Soils) visited the Institute of Agrophysics of the Polish Academy of Sciences, Warsaw, Poland, in October; Dr D. Vaughan (Soil Organic Chemistry) visited research centres in Amsterdam in The Netherlands and Braunschweig and Bonn, Germany, in July; Dr G. Lethbridge (Microbiology) visited research centres in Portland and Nebraska, U.S.A., and Alberta, Canada, in September; Dr G. D. Buchan (Soil Fertility) visited research centres concerned with soil physics in The Netherlands, Denmark, Sweden and Norway in July. Mr E. Paterson (Mineral Soils) visited the University and E.T.H. Zurich, the University of Berne and the Institut für Bodenkunde der T. U. München, to study work in progress on oxide systems, particularly iron and manganese, lecturing at all these centres. Dr N. M. Scott (Soil Fertility) attended a Symposium on sulphur and forage crops held in Wexford in the Republic of Ireland.

U.K. Meetings attended and Lectures given by Institute Staff

A very successful Symposium entitled " Current developments in remote sensing," organized by Mr R. A. Robertson and Dr G. C. Stove, was held at the Institute 16-17 October. It attracted over 50 participants, including representatives from the Swedish Space Agency, F.A.O., Rome, and the

U.K. Remote Sensing Centre at Farnborough. Papers were given by speakers from the Department of Physical Planning of the Grampian Regional Council, The University of Dundee, The Royal Aircraft Establishment and by Dr P. D. Hulme, Mr R. A. Robertson and Dr G. C. Stove of the Institute. A group of some 15 members of staff attended the second inter-institute conference with the Letcombe Laboratory, Rothamsted Experimental Station and The Macaulay Institute at the Letcombe Laboratory in March. Several members of staff, Drs Goodman, MacDonald, Sparling and Vaughan spoke at the meeting. A third conference is planned at RES for 1980, the first having been held in Aberdeen in November, 1977. Dr D. Jones lectured and displayed a poster at the first International meeting of Botanical Microscopy at York University in July and gave an invited lecture at a meeting of the Plant Pathology and Mycology Group at the Royal Botanical Gardens in Edinburgh in May. Several members of staff of the Department of Soil Survey attended and joined in discussions at the joint meeting of the British Society of Soil Science and the Royal Geographical Society in London and a Forest Soils Group in Caithness and Sutherland, where Mr D. W. Futty gave a talk on the soils and geology of the region. Dr M. V. Cheshire, Dr H. A. Anderson and Dr D. J. Linehan presented papers at a meeting of the Agriculture Group of the Society of Chemical Industry in London and Dr Cheshire also read two papers at a Symposium on straw decomposition at Hatfield. Several members of staff of the Department of Soil Organic Chemistry also attended a meeting of the Society of Experimental Botany at York and a Symposium on recirculating water culture at GCRI, Littlehampton. Members of staff of the Department of Peat and Forest Soils presented papers at meetings of the Remote Sensing Society in Durham (Dr P. D. Hulme and Dr G. C. Stove), the Welsh Soils Discussion Group in Swansea (Dr H. G. Miller), the Silvicultural Group of the Royal Scottish Forestry Society in Edinburgh (Dr H. G. Miller) and an International Spaceflight Exhibition in Glasgow (Mr R. A. Robertson and Dr G. C. Stove), which included a display of photographs and maps prepared by the staff of the Department from LANDSAT imagery. Members of staff of the Department of Soil Fertility, Soil Organic Chemistry, Spectrochemistry and Microbiology also attended and spoke at various meetings of the Agriculture Group of the SCI in London during the year and staff of the Department of Statistics attended meetings and conferences of the Royal Statistical Society. Several members of staff of the Departments of Spectrochemistry and Mineral Soils attended the XXII Colloquium Spectroscopicum Internationale and Eighth International Conference on Atomic Spectroscopy, held in Cambridge. Dr R. O. Scott gave a keynote lecture on the application of spectrochemical techniques to soil analysis and Drs V. C. Farmer and B. L. Sharp also presented papers. Dr J. W. S. Reith, Dr M. L. Berrow and Mr J. C. Burridge presented papers at the International Conference on the Management and Control of Heavy Metals in the Environment, London, and at a Society of Chemical Industry Symposium on "Trace Elements in Soils, Plants and Animals," also in London. Dr A. M. Ure gave a plenary lecture at a Chemical Society Symposium on "Inorganic and Organic Pollutants in the Troposphere and Natural

Waters " in Belfast. Dr V. C. Farmer gave lectures on the application of infrared spectroscopy to the characterization of soil allophanes at a meeting of the Clay Minerals Group of the Mineralogical Society in London and to the Dalton Division of The Chemical Society in Lancaster. Dr B. A. Goodman presented two papers on " Electron Paramagnetic Spectroscopy " to the International Conference on Electron Spin Resonance in Inorganic and Biological Systems in Nottingham and at a Mössbauer Spectroscopy Discussion Group of The Chemical Society in London. Mr R. H. E. Inkson gave a lecture to the Agricultural Society of Aberdeen University on " How vital are statistics? " and a series of lectures on experimental design and sampling to postgraduate students of the University Soil Science Department. Dr Darbyshire, Dr Sparling, Dr Lethbridge and Mr Wheatley also gave lectures on microbiology to the same postgraduate students and Dr Darbyshire to microbiology students of the School of Agriculture. Dr T. S. West presented an invited paper on the " Uptake of major mineral elements by plants " at the Rank Prize Funds Symposium on " Food Chains in Human Nutrition " at Kenilworth and gave the First Tom Miller Memorial Lecture at the School of Agriculture of the University of Aberdeen on " The biosignificance of trace elements and their analysis in soils and plants."

Not to be outdone by the staff, two of our postgraduate students gave talks at The Chemical Society meeting on " Research Work by Young Workers in Universities and Industry " at Edinburgh. Mrs Karen Welch spoke on the preconcentration of trace elements for agricultural analysis by spark-source mass spectrometry and Mr (now Dr) S. Cooke talked on the determination of trace gases in the atmosphere by use of the piezoelectric effect.

New Postgraduate Research Students

Two new research students have joined the work of the Institute's staff. Mr M. J. Hepher is working in the Department of Soil Fertility on piezoelectric sensing of air borne gases of agricultural interest being supported by an ARC grant. Mr Lau Chau Ming from Hong Kong is studying atom trapping techniques in analytical atomic spectroscopy, in the Department of Spectrochemistry. The total number of postgraduate PhD researchers in the Institute during the year was thirteen.

Miss Helen Green an SRC student of the University of Aberdeen, although not registered in the Institute, has been studying the complexing of metals by soil organic matter with the equipment available to her here and under the guidance of Dr B. Goodman of the Department of Spectrochemistry who is a co-supervisor of her postgraduate research studies. During the year several students have gained the PhD degree of the University whilst at the Institute: Dr S. Cooke is now on the staff of the Institute's Department of Soil Fertility; Dr S. Forbes is now with Shell Research at Sittingbourne, Kent; Dr J. Khalighie is concluding her work on atom trapping spectroscopy at the Institute as an extension of her doctoral studies. Dr D. A. P. Mackay is now on the staff of the Institute's Department of Statistics and Dr A. R. Morrison is now a Research Fellow at the Chemistry Department of the University of Aberdeen.

The Central Electricity Generating Board offered the Institute funding to allow the appointment of a temporary member of staff to carry out work in the Department of Peat and Forest Soils to study the possible effects of humus and peat decomposition on the acidification of natural waters. Dr W. R. Johnston, Stirling University, has accepted this two-year appointment and has started work in the Institute.

Overseas Research Workers

As well as the postgraduate research students mentioned above, several other long-term workers have visited the Institute from Australia, China, Fiji, Germany, Italy, New Zealand, Spain and the Yemen Arab Republic. Mr Pu Guo-Gang from Hofei University, People's Republic of China, was awarded one of the first Royal Society/Chinese Academy of Sciences Exchange Scholarships to study electroanalytical chemistry at the Institute for one year. We are also very pleased to have Dr and Frau R. Martens of the Institute for Soil Biology, Braunschweig, Federal Republic of Germany, working on Microbiological problems and Dr Valerie Orchard of the DSIR Soil Bureau, Lower Hutt, New Zealand, in the same research area. Also from Australisia came Professor W. F. Pickering of the University of Newcastle, New South Wales, Australia, who studied various investigatory methods, mainly in the Department of Mineral Soils.

Institute Events

The past year has also seen the first meeting within the Institute of the Consultative Committee on Soils Work set up between the three Colleges of Agriculture and the Institute. The brief of the Committee is to exchange information and views on research and development work on Scottish soils and to encourage and promote increased contact and liaison between the groups concerned in all four organizations. It is planned that the Committee will meet annually, but perhaps more frequently at the outset to establish the necessary links and basis for its future meetings.

During the year we have also conducted a series of Package Reviews in which all relevant senior members of staff have taken part in reviewing the whole programme of the Institute and in discussing objectives, progress, difficulties, resources, relevance to future work, etc. This has largely replaced formal lectures by staff at internal colloquia during 1978-79.

Plans laid during the past year-and-a-half for an extension to the main Institute building have had to be shelved because of economic restrictions, but it has been possible to convert some of the space used for storage of soil samples in the main building into two new laboratories for electrochemistry and physics, and permission has been obtained from the DAFS to erect an outbuilding to house the crop work presently being carried out in the main building, and thus allow further " high-grade " accommodation to be converted to laboratories.

The Committees set up to make arrangements for the two Open Days to mark the Jubilee of the Institute have been active during the year and plans are now well advanced for the event. Mr J. G. Currie, a local artist has accepted a commission to make a work of art for the entrance hall of the

Institute to commemorate the Jubilee. The work—a montage of vitreous enamel-on-copper depicting the four seasons in relation to the soil—is now virtually complete and will be unveiled at the first of the two Open Days. The Editorial Committee of the Institute news magazine " Profile " is again to be congratulated on the production of a magazine that seems to be read in places as far-flung as ARC Headquarters and the Thames Valley Institutes. By December, 1979, the magazine will have reached its 41st issue.

The Council of Management met twice, on 25th May and 23rd November. Its discussions centred mainly round the events of the Jubilee and the impact of economic restrictions on the Institute's programmes. Professor Phemister was re-elected Chairman of The Council and Professor J. D. Matthews of the University of Aberdeen became the Convener of the Council's Finance Committee in succession to Principal G. M. Burnett of Heriot Watt University, Edinburgh.

The departmental responsibilities for individual research projects are discussed in the Report as follows:

100	Pedology (Division)	500	Microbiology
200	Spectrochemistry	600	Soil Fertility
300	Soil Organic Chemistry	700	Statistics
400	Plant Physiology	800	Soil Survey

In addition to the research projects, a number of service projects are also listed. When these are non-departmental, provided by Technical Services or Administration, they bear a 900 series identification, while for inter-departmental services for which one department is responsible, the appropriate series number of that department is prefixed by 5. A list of service projects follows that of the research projects.

PROGRAMME OF WORK

RESEARCH PACKAGES AND ASSOCIATED PROJECTS

PACKAGE 1: The study of the development and composition of mineral soils and their size fractions.

Objective: To elucidate the factors that control the composition and contribute to the physical and chemical properties of mineral soils. So to provide information that could help to explain differences in soil structure and soil behaviour.

(a) Characterization of Minerals and Major Constituents

Projects

101 Scottish soil types: chemical and physical characterization in relation to development.

103 Soil mineralogy: relationship with soil type and soil properties.

104 Minerals: alteration during weathering and soil development.

107 Mineral and organic soils: development of chemical and instrumental methods of examination.

108 Mineral and organic soils: characterization by products of thermal decomposition.

109 Mineral and biological materials: structure and composition by electronoptical and electron probe methods.

(b) Trace Element Characterization

201 Distribution and location of trace elements in soils: effect of soil parent material and drainage conditions.

204 Geochemical distribution and pedological behaviour of trace elements.

205 Development of techniques for the determination of trace elements: direct reading methods and computer processing.

206 Development of flame emission and atomic absorption methods: instrumentation and techniques for trace and major elements.

703 Development of computer techniques and programs.

PACKAGE 2: The study of the nature and surface properties of soil clay minerals and mineral-organic matter complexes.

Objective: To investigate the factors involved in the surface and colloidal reactions of soil minerals, particularly of the clay minerals and complexes that participate in the mobilization or binding of plant nutrients in the soil.

Projects

105 Soil colloids: nature, origin and behaviour of inorganic, organic and organomineral complexes.

106 Surface characteristics of soil particles.

207 Characterization of soil minerals and study of their surface properties and weathering by infrared methods.

304 Nature, distribution and properties of humic soil substances.

PACKAGE 3: The survey and classification of the mineral soils of Scotland.

Objective: To map and classify soils systematically according to their parent materials, pedological drainage and other field characteristics: to produce land use capability maps. The systematic survey identifies soil types and facilitates other investigations of the cause of differences in their fertility and other soil properties.

Projects

801 The systematic survey of Scottish soils.

804 Studies of soil structure and genesis.

PACKAGE 4: The study of the nature and properties of soil organic matter.

Objective: To determine the nature of the organic materials in soils at different stages of decomposition under different pedological conditions to ascertain their contribution to the physical structure and chemical behaviour of soils and their effect on the growing plant.

Projects

208 Characterization of soil organic matter by infrared and ultraviolet methods.

303 Nitrogenous constituents of soils, peat and leaf litter, relationships with co-occurring macromolecules.

305 The synthesis and degradation of polysaccharides and related constituents of soil organic matter.

307 Characterization of soil humic substances by means of their paramagnetic properties.

309 The effect of organic constituents of soil on the growth and nutrition of plants, with particular reference to processes involving the root.

311 The effects of organic constituents of soil on biochemical processes in plants.

PACKAGE 5: The investigation of the role of soil microorganisms in soils and in soil-plant relationships.

Objective: To assess the effects of soil microorganisms in the transformation of organic material in soil and to study the interactions between soil microorganisms and plants in order to ascertain the nature of their contribution to crop growth yield.

Projects

301 Chemical and biochemical investigations of organic material of microbial origin.

502 Production of cell material and by-products of soil microorganisms.

503 Microorganisms involved in the decomposition of peat and its components.

507 Ultrastructure and chemical composition of soil fungi, including plant pathogens.

508 Soil-borne fungal parasites.

510 Investigation of soil protozoan populations.

512 Microbial transformation of soil organic matter.

513 Interrelationships of soil actinomycetes, bacteria and protozoa with plant-roots.

514 Asymbiotic nitrogen fixation by soil microbes in the rhizosphere of agricultural plants and in peat.

PACKAGE 6: The study of the nature and distribution of organic soils and peat in Scotland.

Objective: To survey and classify the peat deposits and organic soils in Scotland and to study their utilization and potential fertility for agriculture, horticulture and forestry.

Projects

110 Organic soils: moisture retention and root development.

111 Organic soils: site capability and amelioration.

112 Scottish peat deposits: survey, classification and characterization.

113 Pollen and plant-fossil analyses: post-glacial vegetational and climatic changes.

114 The use of peat and peat products in agriculture and horticulture.

116 Nitrogen mineralization: factors controlling release of nitrogen immobilized in peat and humus.

PACKAGE 7: Investigations on the fertility of soils and the yield of agricultural crops.

Objective: To investigate factors controlling, and to study means of improving, the fertility of agricultural soils by related field, pot and laboratory studies on soil nutrient status, fertilizer usage and crop yield.

(a) Soil-Nutrient Relationships

Projects

203 Forms of occurrence of trace elements in soils and the mechanism of their movement towards the plant root.

317 The nature and properties of organically bound phosphate in soils.

601 Inorganic soil phosphorus and sulphur: evaluation of available forms and effects of fertilizers.

602 Organic phosphorus and sulphur in relation to soil type and nutrient supply.

603 Available nitrogen in soils.

604 Soil acidity: aluminium solubility and cation exchange equilibria in different soil types.

605 Anion sorption: kinetics and equilibria of phosphate reactions in relation to soil composition.

611 Soil potassium and magnesium: distribution, solubility and availability in different soil series.

614 Electrochemical studies on soil-nutrient-plant relationships.

(b) Soil-Plant Relationships

607 Growth, development, nutrient accumulation and yield of field crops: effects of environment and management.

608 Field responses to nutrients: soil type effects and prediction of fertilizer requirements.

609 Trace element status of soils and crops: effects of soil type; diagnosis of deficiencies and excesses.

610 Assessment of lime and nutrient status of soils.

612 Soil physical conditions and crop growth.

701 Theory of experimental design and statistical analysis.

702 Relationship of crop yield and composition to soil properties, and the numerical classification of soils.

PACKAGE 8: The study of factors affecting crop composition.

Objective: To investigate the effects of soil conditions on crop composition and to study plant-physiological aspects of soil-plant relationships. The content of the plant and its individual parts may have particular reference to soil-plant-animal problems related to both major and trace nutrients.

Projects

202 Trace element uptake by plants: distribution in different species and plant parts.

401 Iron and copper metabolism of plants.

402 Uptake and physiological effects of chelated trace elements on plants.

407 Salt absorption: physical and metabolic aspects.

408 Nitrate reductase and molybdenum-copper interactions in plants.

606 Inorganic and organic constituents in crops: forms, patterns and balance in relation to age and yield.

613 Development and application of radioisotope techniques.

PACKAGE 9: The study of the fertility of forest soils and other non-agricultural soils and their natural vegetation.

Objective: To study the nutrition of conifers and other non agricultural crops on forest soils, peats and other soils of limited capability. To study the natural vegetation in relation to soil type and to consider means of improving the utilization of marginal land.

Projects

115 Conifer nutrition: nutrient cycling, tree growth and influence of fertilizers.

117 Nutrient deficiencies in conifers: diagnosis and amelioration.

802 Plant communities and their relation to genetic soil types.

A research grant from the Forestry Commission contributes towards the cost of the forest soil projects.

SERVICE PROJECTS

Non-Departmental

Projects

901 Provision of Instrument Workshop facilities.

902 Provision of Photographic facilities.

903 Provision of specialized materials and equipment.

Departmental

Projects

5107 Mineral and organic soils: application of chemical and instrumental methods of examination.

5205 Application of techniques for the determination of trace elements: direct reading methods and computer processing.

5206 Application of flame emission and atomic absorption methods for trace and major elements.

5313 Provision of analytical facilities employing special equipment.

5314 Supervision and maintenance of general glasshouse facilities.

5613 Provision of radioisotope facilities.

5701 Production of designs for experiments and statistical analysis of data.

5703 Data preparation and computer processing.

DIVISION OF PEDOLOGY

During the year the Department of Pedology became a "Division" and the previous Sections individual Departments, the Section of Chemistry and Mineralogy being renamed the "Department of Mineral Soils," a title that more accurately reflects its interests in relation to those of the "Department of Peat and Forest Soils." Dr R. C. Mackenzie remain in general charge of the Division, but is also head of the Department of Mineral Soils with Mr B. D. Mitchell as deputy head. Mr R. A. Robertson is head of the Department of Peat and Forest Soils. The work of the Division carries on essentially that of the previous Department—namely, investigations aimed at obtaining (a) a better understanding of the origin and properties of the soil and (b) information relevant to the better utilization of poor, highly organic soils.

The major advance during the year has undoubtedly been in the use of remote sensing as a tool in peat survey. The solid-state digitizer, acquired last year, together with the stereoplotter, the image analyser in the Department of Microbiology and various facilities kindly made available by the Royal Aircraft Establishment, Farnborough, have enabled an assessment to be made of the extent to which remote sensing techniques can be utilized[1] and it is probably fair to state that reality exceeded expectation. This work culminated (just after the period covered by this report) in a meeting at the Institute organized by Mr Robertson and Dr Stove, at which members of regional planning authorities, university personnel, staff from interested institutions and representatives of international and commercial organizations met to discuss the value of various remote sensing techniques in different fields. In peat survey, it is now undoubted that remote sensing can reduce drastically the amount of ground traverse required and, when used with photogrammetric and computer techniques, the time for map production, thus increasing productivity and reducing costs.

In studies on mineral soils, a development that deserves mention is the study of the weathering of feldspars, which, using a variety of instrumental techniques along with careful observation, has shown that weathering commences at surface sites of lattice dislocations, where strain would be expected. These observations show no sign of the amorphous coating that was previously thought to exist and throws new light on the weathering process.

References:

1. Remote sensing in peat-resource and land-use survey. By G. C. Stove and R. A. Robertson, *ARC Res. Rev.*, 5, 21-27, 1979.

1. MINERAL SOILS

R. C. Mackenzie

A mineral soil has been defined as a soil consisting predominantly of, and having its properties principally determined by, mineral matter: although it usually contains <20 per cent organic matter, it may have an organic surface layer which can be up to 30 cm thick.

In the assessment of factors controlling the development, composition, constitution and properties of such soils, samples from other departments of the Institute and from outside bodies, at home and overseas, have been examined, since only by this means can norms be assessed and limits drawn. Such work frequently, also, leads to fruitful collaborative studies.

Soil Analysis

Chemical Studies. Systematic chemical and physical tests have been completed on profile samples collected in 1977 and are well advanced on those collected in 1978. Samples have also been analysed for other departments of the Institute and for outside bodies such as the North of Scotland College of Agriculture. The facility for C, H and N analyses has been particularly well utilized. 101, 201, 304, 512, 801

In view of the success of the pilot study, in collaboration with the Department of Statistics, of the Institute soil data bank, transfer to the bank of field and laboratory data on profile samples, currently stored on conventional record cards, has been initiated. Priority is being given to the most important of the recognized soil associations and to the profiles for which much specialized data are available. It is intended that eventually all new results will be fed directly into the computer store. In assessing such data, it must be remembered that the significance of results for profile samples (*i.e.* point samples) can be assessed only when the variation in values over an area of uniform material is known. Statistical examination of some results for samples taken within the same pedological feature at distances varying from 0·5 m to 8 km showed[1] that variations could be quite considerable over distances of only half-a-metre. 101, 108, 703, 801

Soils of the principal soil series mapped in the Orkney Islands (Sheets 118, 119, 120, 121, part 117) have had their contents of major elements and highly disordered aluminosilicate determined by X-ray fluorescence spectroscopy and selective chemical procedures. X-ray fluorescence measurements made in conjunction with a visiting research worker have shown that the sulphur content of herbage samples from Egypt extends over a slightly wider range (0·1-0·8%) than that of herbage samples recently examined for the Rowett Research Institute (0·1-5·5%). 101, 104, 105, 801

The portable field probe for sampling the soil atmosphere, designed and constructed in collaboration with Technical Services, gives the degree of replication necessary to allow for local variations in soil gas composition. This probe, along with mass spectrometry to determine gas concentrations above 0·1 per cent, has now been used to examine the amounts of various gases present in the atmospheres associated with two soils having impeded gaseous exchange with the atmosphere[2]. The monitoring of major elements in stream water, referred to in last year's report, has been extended to include a catchment area on the Strathfinella Association and relatively simple soil-water samplers have been inserted in A, B and C horizons of the dominant series of each catchment. Preliminary results indicate that the concentration of major elements in soil water is generally lower than that in stream water: thus, for the Countesswells Association the mean value for silica in the soil water (6 ppm) is only about half that in the stream water (12 ppm). This investigation continues. 101, 105, 107, 108

Electron probe microanalysis along with scanning electron microscopy is being extensively used to determine the location of specific elements in various soil features[3]. For example, in B_H and B_s horizons of podzolic profiles on sand and gravel, as well as in "moor-pans" (organic-bound sand layers generally occupying depressed sites), aluminium has been found to be dominant in all the coatings; moor-pans always contain phosphorus and sulphur and have low iron and relatively high calcium contents. 107, 109, 804

Thermoanalytical Studies. Thermal analysis developed essentially from the curiosity of early man regarding the effect of heat on materials[4, 5] and the number of techniques now available is considerable[6], although differential thermal analysis (DTA), differential scanning calorimetry (DSC) and thermo gravimetry (TG) tend to predominate[7, 8, 9]. A recent DSC study has shown that adsorbed anions affect the surface hydroxyl groups on samples of synthetic goethite[10] and akaganéite, although in the latter compound the surface hydroxyl groups are less stable and decompose some 50-100°C below the main dehydroxylation temperature. 101, 103, 104, 105, 107

Soil Minerology

The minerals in the soil, derived either directly from or through weathering of the parent rock, control to a considerable extent the soil fabric and contain the nutrient capital of the soil, thus determining its inherent fertility. Moreover, because of associations between minerals and between mineral and organic matter, a large range of investigational methods have to be used for their examination. A preliminary study of the potassium reserves and mineralogy of profiles from the principal soil associations in Scotland has now been completed. In this study, dilute hydrochloric acid was employed as an extractant, not because the extractable potassium is necessarily that available to plants, but rather to provide a uniform basis for further investigations: a technique for quantitative X-ray diffraction of minerals in different size fractions has been developed. Results show that the amounts of extractable potassium in soils on tills derived from granite, gneiss and micaceous metamorphic rocks and on estuarine and lacustrine clays are high, whereas those in soils developed on tills derived from lavas and Carboniferous sediments and on fluvioglacial sands are low. 101, 103, 104

Feldspars represent an important potential source of plant nutrients in soils, even although release of nutrients through weathering is generally slow. The extensive etching of feldspars in Scottish soils, as revealed by scanning electron microscopy, was thought to be due to dissolution of the feldspar occurring at locations representing the emergence of structural dislocations. To test this hypothesis, matching 001 and 010 cleavage surfaces of a microcline-perthite were hydrothermally etched. Both sets of faces rapidly developed mirror-image arrays of etch pits transecting the perthitic lamellae and occurring at the interface with the potassium-rich host: etching also seemed to occur preferentially along the direction of pericline twinning. In collaborative studies with the Department of Microbiology, it has been observed that the lichen *Pertusaria corallina* during its growth generates oxalic acid which etches the calcium-bearing feldspars in basalt and leads to precipitation of calcium oxalate in the lichen thallus[11]. At the same time, ferromagnesian minerals are decomposed leading to the formation of the poorly crystalline mineral ferrihydrite and some very highly disordered gel. Work is currently in progress to investigate the effect of colonization of the surface of serpentinite by the lichen *Lecanora atra*. 104, 109, 508

Whereas internal erosion of the soil is mainly responsible for the silting-up of tile drains in fine-textured surface-water, low-humic gleys[12], further observations show that chemical and microbial processes probably predominate in the formation of ochreos deposits in tile drains in humic gleys. These deposits consist mainly of iron oxides (ferrihydrite and lepidocrocite) and organic matter and contain well-formed bacterial relics of *Sphaerotilus natans*, a sheath-forming bacterium frequently found in aquatic environments. Small occlusions of the manganese oxide birnessite have also been found. 103, 106, 109, 801

In collaborative studies with the Department of Spectrochemistry it has been found that titanium and vanadium in the eluvial horizons of Scottish podzols are not leached out on weathering but accumulate in the clay fraction[13] and that the heavy-metal content of serpentinite soils in north-east Scotland is related to their mineralogy[14]. Mössbauer spectroscopy has shown that most of the iron in a series of trioctahedral chlorites of varying composition occurs as Fe^{2+}: heat treatment and acid extraction cause low-iron chlorites to be partially vermiculitized, but high-iron species do not react in this manner[15]. 101, 104, 109, 201, 203

Fresh basalt from Morven, Argyllshire, has a cation-exchange capacity of 10 m-eq/100g because of the presence of a swelling mineral. This mineral has been identified as a chlorite low in aluminium but relatively high in magnesium and iron: it is believed to have been formed by late-stage alteration of labradorite. 104, 508

A discussion on penecontemporaneous weathering of Old Red Sandstone in the Midland Valley has now been published[16]. 104

Clay Fraction. Because of the nature of the minerals it contains and its large area of reactive surface, the clay fraction has a disproportionate effect on soil properties. An assessment of the development of clay mineralogy and its present position leads logically to the conclusion that in the foreseeable future most attention must be paid to the surface characteristics and properties of both the crystalline and the highly disordered components[17].

However, the mineralogical composition of soil clays must not be neglected[18], as such information is essential in assessing surface properties. Currently, clay fractions separated from profile samples from the Tomintoul area (Sheet 75) are being examined mineralogically. 103, 104, 105, 107

A ferriferous beidellite with, apparently, interlayer organic material has been found in Vertisols formed on alluvial terraces of the Ceyhan River in Turkey: this series of terraces forms a valuable chronosequence, enabling information to be obtained on variation of clay mineralogy with time[19]. A ferriferous beidellite has also been found in typical Vertisols and Entisols from the Blue Nile plain of the Sudan[20]. A study of some Saudi Arabian soils, in collaboration with the Faculty of Agriculture, University of Riyad, has shown that the wadi soils examined contain considerable amounts of palygorskite, whereas the mineralogy of soils developed on sedimentary rocks reflects that of the parent strata. The results suggest that the palygorskite was formed *in situ*[21]. Diseased tissues from those suffering from a non-filarial form of elephantiasis in Cameroon contain soil particles. Since a collaborative study with the London School of Hygiene and Tropical Medicine revealed no relationship between soil-clay mineralogy and incidence of the disease, attention is now being concentrated on the 2-20μm particles. In a collaborative study with Massey University, New Zealand, it has been found that andesitic volcanic glass weathers more rapidly than rhyolitic, probably because of its occurrence as fine soft particles with a relatively high aluminium content[22]. 103, 104, 105, 107, 109

An iron oxide complex occurring in red mottles in deeply weathered granite on Bennachie, Aberdeenshire, was originally thought, on X-ray diffraction and infrared evidence, to be an interstratified smectite-hematite. However, chemical analysis is not consistent with this hypothesis and it is now believed to be a silica-iron oxide complex of as yet unknown structure. The general theory for one-dimensional X-ray scattering by interstratified minerals containing non-centrosymmetric layers has now been elucidated[23].
103, 104, 105, 109

Further studies on imogolite in conjunction with a visiting scientist and in collaboration with the Department of Spectrochemistry, have led to the recognition in Italian soils of both imogolite and the less highly ordered form proto-imogolite[24, 25] and to assessment of the stability, free energy and heat formation of imogolite[26]. The chemical structures of natural and synthetic aluminosilicate gels have also been investigated[27].
103, 104, 105, 109, 207

Surface Properties of Soil and Clays. The layered manganese oxide buserite, which gives a basal spacing depending on the saturating cation[28], can also intercalate quaternary ammonium salts to give a highly expanded structure—*e.g.* d_{001} for dodecyclammonium buserite is 25·4 Å compared with 7 Å for K-buserite. The structure and properties of these intercalated species are being further investigated. It has now been established that the iron oxyhydroxide akaganéite (β-FeOOH) can be synthesized in the laboratory at PH values less than 2·5 and when the fluoride and/or chloride ion

concentration relative to iron is greater than 0·1—conditions unlikely to be encountered in soils and sediments except under exceptional circumstances.
105, 106, 109, 203

Cation-exchange capacities of surface horizons of podzolic soils determined at pH values in the range 3-9 showed an almost linear relationship with pH; however, for surface horizons of brown forest soils the linear relationship broke down at higher pH values. Whether or not these observations can be related to differences in the nature of the organic matter is being further investigated. 101, 106, 801

The mercury porosimeter acquired last year enables measurement of pores in the 3·5-7500 nm range, thus overlapping with the range over which nitrogen adsorption can be usefully used (0·35-15 nm). It is now possible, therefore, to extend studies to macro samples of soil and to soil cores. The instrument has proved very satisfactory in practice and is now being used in the physical characterization of a hydrologic sequence of soils from the Foudland Association. 101, 106, 801

Organic and Biological Materials. A technique of pyrolysis-mass spectrometry (which gives greater reproducibility for a wider range of products, can be more readily used quantitatively with pattern recognition methods and is potentially more rapid than methods using gas chromatography as an intermediate) has been developed during the year. When pyrolysis products from the Curie-point pyrolyser are introduced, in a stream of helium, into the mass spectrometer and spectra are obtained using low-voltage ionization, molecular ion series characteristics of many biological species in soil organic matter (*e.g.* polysaccharides, lignin-derived materials, polypeptides and sulphur compounds) can be recognised. The method has been particularly successful with lignins, fragmenting them into various readily identifiable methoxyphenols. 108

The same technique has now been used to study the changes occurring during the early stages of humification in basin peats and peaty podzols. Polysaccharides and lignin decreased in amount on humification, whereas compounds yielding pyrroles and aromatic compounds increased in abundance. Ratios of several product ion intensities (*e.g.* methoxyphenols to simple phenols, dianhydromonosaccharides to furan ring compounds and aromatic to aliphatic hydrocarbons) can be sensitive indices of the degree of humification and some results have suggested structural evidence—such as the presence of a relatively stable component that could be an altered polysaccharide capable of pyrolysis to furan compounds. In collaboration with the Department of Soil Organic Chemistry, the method is showing promise in the characterization of humic and fulvic fractions extracted and treated in different ways. 108, 304, 305

Pyrolysis-gas chromatography studies on model compounds for soil humic substances have been extended. Cyclopent-2-ene-l-one, a product of pyroloysis of polycarboxylic acids and fulvic acids, can be used in assessing humus type as the amount obtained increases with humification. The abundance of acetic acid, phenols and aromatic hydrocarbons increases with the molecular weight of the polymer. Polysaccharides, proteins, field-drain deposits and various organic acid derivatives prepared by the Department of Soil Organic Chemistry from soil extracts and model compounds, have also been examined by gas chromatography-mass spectrometry. Studies, in collaboration with the Departments of Soil Organic Chemistry and Spectrochemistry, on the determination of the structures of, and bond-linkages in, soil polysaccharides have been published[29]. 108, 208, 304, 305

References:

1. Variability of organic matter and exchangeable cations within the A_2 horizon of an iron podzol. By J. M. Bracewell, G. W. Robertson and J. Logan. *J. Soil Sci.*, **30**, 327-332, 1979.
2. Rapid representative sampling of soil gases and their determination by mass spectrometry. By G. W. Robertson and J. M. Bracewell. To appear in *J. Soil Sci.*
3. Application of scanning electron microscopy and microanalysis to the study of soil mineralogy. By W. J. McHardy, *Geol, appl. Idrogeol.*, **12**, 213-233, 1977.
4. Some highlights from the history of thermal analysis. By R. C. Mackenzie, *Zborn. VIII Celostát. Konf. term. Analyze*, 353-356, 1979.
5. *De Calore:* prelude to thermal analysis. By R. C. Mackenzie. To appear in *Thermochim. Acta.*
6. Nomenclature in thermal analysis. By R. C. Mackenzie. To appear in *Treatise on analytical chemistry*—2nd ed., Pt. 1. Edited by I. M. Kolthoff, P. J. Elving and C. B. Murphy. New York: Wiley Interscience.
7. Variable atmosphere DTA in identification and determination of anhydrous carbonate minerals in soils. By S. St J. Warne (University of Newcastle, NSW, Australia) and B. D. Mitchell, *J. Soil Sci.*, **30**, 111-116, 1979.
8. Complementary Techniques. By R. C. Mackenzie. To appear in *Thermogravimetry*. Edited by J. P. Redfern and C. J. Keattch. London: Butterworths.
9. 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. London: Butterworths.
10. Influence of adsorbed anions on the dehydroxylation of synthetic goethite. By E. Paterson and R. Swaffield. To appear in *J. Therm. Analysis.*
11. Microbiological weathering of a basalt by a saxicolous lichen, *Pertusaria corallina* (L.) Arnold. By D. Jones, M. J. Wilson and J. M. Tait. Submitted to *Lichenologist.*
12. Erosion deposits in tile-drained soils. By E. Paterson and B. D. Mitchell, *Agri. Water Management*, **1**, 311-317, 1978.
13. Origin and significance of extractable titanium and vanadium in the A horizons of Scottish podzols. By M. L. Berrow, M. J. Wilson and G. A. Reaves, *Geoderma*, **21**, 89-103, 1978.
14. The mineralogy and heavy mineral content of some serpentinite soils in north-east Scotland. By M. J. Wilson and M. L. Berrow, *Chem. Erde*, **37**, 181-205, 1978.
15. Mössbauer spectra of chlorites and their decomposition products. By B. A. Goodman and D. C. Bain, in *Int. Clay Conf, 1978*, 65-74. (M. M. Mortland and V. C. Farmer, eds.), Amsterdam: Elsevier, 1979.
16. Penecontemporaneous weathering of the Old Red Sandstone in the Midland Valley of Scotland—discussion. By M. J. Wilson, *Scott. J. Geol.*, **15**, 66-67, 1979.
17. Clay mineralogy—whence and whither? By R. C. Mackenzie, in *Int. Clay Conf. 1978*, 1-14. (M. M. Mortland and V. C. Farmer, eds.), Amsterdam: Elsevier, 1979.
18. Interlayer and intercalation complexes of clay minerals. By D. M. C. MacEwan (Hythe, Kent) and M. J. Wilson. To appear in *X-ray identification and Crystal Structures of Clay Minerals.* Edited by G. Brown and G. W. Brindley. 3rd ed., London: Mineralogical Society.

19. Clay mineral studies of a Vertisol chronosequence in southern Turkey. By N. Güzel and M. J. Wilson. Submitted to *Geoderma.*

20. Comparative study of a Vertisol and an Entisol from the Blue Nile clay plains of Sudan. By M. J. Wilson and B. D. Mitchell. To appear in *Egypt. J. Soil Sci.*

21. Clay and silt mineralogy of some soils from Qasim, Saudi Arabia. By A. S. Mashhady and M. Reda (University of Riyad, Saudi Arabia), and M. J. Wilson and R. C. Mackenzie. To appear in *J. Soil Sci.*

22. A comparative study of the morphology, chemical composition and weathering of rhyolitic and andesitic glass. By J. H. Kirkman and W. J. McHardy. Submitted to *Clay Minerals.*

23. General theory of one-dimensional scattering of X-rays from interstratified minerals. By P. D. Cradwick, *N.Z.Jl. Sci.*, **21**, 409-411, 1978.

24. Identification of imogolite in some volcanic soils from Italy. By P. Violante (Università degli Studi di Napoli, Italy) and J. M. Tait, *Clay Minerals*, **14**, 155-158, 1979.

25. Imogolite and proto-imogolite in an Italian soil developed on volcanic ash. By V. C. Farmer, A. R. Fraser and J. M. Tait, F. Palmieri and P. Violante (Università degli Studi di Napoli, Italy) and M. Nakai and N. Yoshinaga (Ehime University, Japan), *Clay Minerals*, **13**, 271-274, 1978.

26. The stability, free energy and heat of formation of imoglite. By V. C. Farmer, A. R. Fraser and J. M. Tait, *Clay Minerals*, **14**, 103-107, 1979.

27. Characterization of the chemical structures of natural and synthetic alumino-silicate gels and soils by infrared spectroscopy. By V. C. Farmer, A. R. Fraser and J. M. Tait, *Geochim. Cosmochin. Acta*, **43**, 1417-1420, 1979.

28. Reversibility of lattice collapse in synthetic buserite. By M. I. Tejedor-Tejedor (University of Madrid, Spain) and E. Paterson, in *Int. Clay Conf. 1978*, 501-508. (M. M. Mortland and V. C. Farmer, eds.), Amsterdam: Elsevier, 1979.

29. Structural studies on the polysaccharides. By M. V. Cheshire, J. M. Bracewell, C. M. Mundie, G. W. Robertson and A. R. Fraser, *J. Soil Sci.*, **30**, 315-326, 1979.

2. PEAT AND FOREST SOILS

R. A. Robertson

The work of the department, embracing eight inter-related projects, is primarily concerned with the classification and evaluation of Scottish peat resources and the improvement in productivity of peat and other marginal land.

During the year, significant advances have been made in the development and application of remote sensing techniques, including space imagery, for peat, vegetation and land-use surveys. A feature of this work has been the close collaboration with the Space Branch, Royal Aircraft Establishment, Farnborough, whose highly specialized equipment for image digital processing and interpretation is being increasingly used to the mutual advantage of both organizations. Likewise, co-operation with the Forestry Commission, Research and Development Division, and the Central Electricity Generating Board has greatly helped to advance studies on the nature and effect of input from the atmosphere of elements, including those in " acid rain," to managed forests and natural ecosystems.

Developments in photogrammetric, digitizing, computer and field experimentation techniques have attracted visits from a growing number of scientists and technologists, including representatives from the Finnish Forestry Society, the Forest Research Institute of New Zealand, the Institute of Geological Sciences, the Institute of Terrestrial Ecology, the Nature Conservancy Council, the Soil Survey of England and Wales, the Universities of Aberdeen, Dundee and Glasgow, and many commercial organizations. Close collaboration has been maintained with the British Steel Corporation, the Department of Agriculture and Fisheries for Scotland, the Department of Industry (Space Division), the Highlands and Islands Development Board, Regional and District Councils, the Scottish Development Department and many other agencies interested in peat research and development. In May, the department hosted a visit to Scotland by Prof. Mälkönen, Soils Department, Finnish Forest Research Institute.

The department is particularly glad to welcome, from 1st October, 1979, Dr W. R. Johnston, who has been appointed on a grant provided by the Central Electricity Generating Board for a period of two years during which he will investigate the contribution made by humus and peat to soil water acidity.

Peat Survey and Evaluation

Peat resource survey and evaluation continue to provide information of direct value to agriculture and forestry and to development agencies involved in land-use planning and the utilization of peat for horticultural and industrial purposes. The results of this work are incorporated in appropriate Soil Survey Memoirs[1] and in more detailed topographic and thematic maps and reports prepared for limited circulation.

110, 111, 112, 114, 115, 801

In collaboration with the Department of Soil Survey, field work in the Kinross, Elie and Edinburgh areas (Sheets 40, 41 and 42) and in the Central Highlands (Sheet 74) is nearing completion, and preparation of contributions for the Orkney Islands and Stirling Memoirs is well advanced. A series of user-orientated maps at a scale of 1:50,000 and an accompanying report have been submitted to the Central Regional Council in support of requirements to prepare regional structure plans. The maps not only indicate the nature and distribution of peat resources within the region but also identify those where peat it currently being produced commercially, those with high or limited potential for future development and those suitable only for forestry, rough grazing or recreation. 112, 114, 801

At the request of the Highlands and Islands Development Board, a detailed topographic and stratigraphic survey of an area of blanket bog adjoining the Barvas Road, north-west of Stornoway, Isle of Lewis, has been carried out to assess the potential of the site for a peat development project. Results of field and laboratory investigations indicate that the depth, quantity and quality of the peat and drainage characteristics are suitable for the mechanical winning and harvesting of air-dry sod peat for use as domestic fuel. Also, on behalf of HIDB and the Highland Regional Council, further surveys have been undertaken in Caithness to complete a peat resource inventory of the area and to assess the development potential of different sites, taking into account the reserves and quality of peat available. Information acquired in the course of field surveys is being constantly applied to problems of devising improved classification systems for peat and peatland vegetation[2, 3]. 112, 114

Systematic photogrammetric mapping of peatland vegetation and land-use categories in the Isle of Lewis at 1:25,000 scale has progressed satisfactorily. Using the solid-state digitizer and recently developed software, the first digital terrain profiles of the Arnish area have been transmitted on line from the stereoplotter to the main computer, where the data are automatically edited and printed on the graph plotter. Similarly, photogrammetric data from the Barvas development area have been digitized and stored in a form that enables topographic and thematic maps and sections to be produced at any desired scale. An improved program has been devised for the absolute scaling and orientation of imagery used in the stereoplotter. In addition, off line digitizing and editing systems for photogrammetric operations, controlled by a PET mini-computer, have been successfully introduced for small to medium scale mapping projects. 111, 112, 5703

Research on the enhancement and interpretation of LANDSAT multi-spectral imagery is being carried out in close collaboration with the Space Branch, Royal Aircraft Establishment, Farnborough, which is now the National Point of Contact (NPOC) with the European Space Agency (ESA) and provides a National User service of film copy products and special processing facilities. Detailed photogrammetric plots of sample areas in north-west Lewis have been used as controls to assess the usefulness of each spectral band for identifying peatland and vegetation types at scales of 1:250,000 and 1:100,000. Results indicate that, whereas some additional features such as peat cuttings and cut-over areas are, after contrast enhancement, more readily detectable on the green and red bands, the near-infra red band is the most useful for identifying and delineating peatland and other categories. For this reason, the first detailed classification of peatland types in Lewis, interpreted from space imagery using the Optomax image analyser at the Institute and the Plessy IDP 3000 image processor at RAE, Farnborough, was completed using this band[4, 5, 6]. 112

On the Tolsta sheet, plotted photogrammetrically at a scale of 1:25,000, sample areas were selected which could be precisely identified and located on the LANDSAT image, using known ground control points. Within these " classifier blocks ", the areas of peatland and other terrain categories were measured and compared with those enhanced and identified on the space imagery. A high degree of areal correlation ($v=0 \cdot 905$) and consistency was obtained[7]. About 80% of the total study area (100 km^2) is peat-covered, the remainder comprising fresh water lochs (10%) and cultivated land and coastal dunes (10%). Intact or virgin peat constitutes about 45% of the total peatland area and moderately eroded peat and shallow peat and rock a further 30% and 16%, respectively. Active peat cuttings account for 6% and unreclaimed cut-over sites the remaining 3%.
112

In collaboration with Grampian Regional Council, ground truth surveys of sample farms in the Laurencekirk area have been carried out to obtain precise information on the nature and distribution of crops at times of satellite overpass. Subsequent experiments on the IDP 3000 at Farnborough have indicated the potential of LANDSAT multi-spectral imagery in distinguishing and delineating areas of barley, grass, cut-grass, potatoes, peas, woodland and bare soil. 112

Aerial surveys of specific areas and transects have continued using a modified air-survey rig mounted on a Cessna 172 aircraft. During the spring, summer and autumn, ten separate sorties were flown to acquire additional vertical stereo and oblique colour and false colour photography. In this way, seasonal changes in ground conditions are being monitored and, where flights are timed to coincide with satellite overpass, used to classify and correlate LANDSAT reflectance values. 112, 901, 902

Pollen Analysis and Quaternary Research

Pollen analysis of several sample series from shallow and deep blanket peat deposits in Shetland[8, 9] has added to the accumulating data on the vegetational history of these islands. In such exposed northern regions, evidence of an arboreal constituent in the vegetation is normally minimal, but at certain sites, e.g. Ollaberry and Oxnabool, the pollen record indicates that *Betula*, *Alnus* and even *Pinus* were formerly components of the vegetation, albeit in small amounts. The Shetland Islands are remote from the nearest extraneous source of wind-borne pollen, the mainlands of Scotland and Norway being some 200km and 360km distant, respectively. It is, therefore, likely that the arboreal pollen grains preserved in the peat were indigenous, thus providing evidence that trees once grew on what is now open moorland. 113

Palynological and macrofossil studies of several lake sediment and peat cores, also from the Shetlands, are in progress, and samples have been submitted for radiocarbon dating in order to establish a time scale for vegetation change and rate of peat development. A trisodium pyrophosphate method of treating samples with a low pollen content has given satisfactory results and has now been adopted as one of the standard procedures. 112, 113

A pollen diagram from an 8 m-deep confined basin mire at an altitude of 364 m in the eastern Grampians has shown that the deposit dates from the late Boreal period, some 7000 years ago. The mean rate of accumulation, over 11 cm per 100 years, is considerably faster than that calculated for other deep mires in the same area. 113

The pollen data bank on the main computer is now complete and editing of site records has provided a statistically representative set of data for Scotland as a whole, thus enabling the production of refined isopollen maps of the main species recorded in all pollen zones. To provide a quantitative spatial evaluation of the isopollen maps and to establish the existence of any significant regional trends, the site data for each species and pollen zone were subjected to trend surface analyses. Regional trends across Scotland in a north-south and east-west direction were then plotted and evaluated for significance. Residual trends were also computed and plotted and the results synthesised into a meaningful pattern of regional and local variations. Multivariate techniques, including principal components analysis, were subsequently used to establish the significance of stratigraphic clusters in the vertical plane at each site, thus testing the significance of the original zoning method. This has verified that the zoning technique adopted was statistically correct, and hence, the resulting trends and conclusions significant. 112, 113

Root and Moisture Studies in Peat

The effect, on the physical characteristics of blanket peat, of surface seeding is being investigated at selected sites on the Isle of Lewis. Although no mechanical cultivation or drainage was carried out, the change from heath to grassland vegetations has been accompanied by a marked increase in the degree of decomposition of the peat in the upper horizons and by a significant reduction in pore volume from 89·9% to 86·3%. However, since the treatments have resulted in an average reduction of 10% in the field moisture content, the air/water balance at the improved sites has actually been greatly enhanced. Furthermore, the combined effects of shell sand application, decomposition and compaction have resulted in a near doubling of bulk density values in the top 10 cm of the soil profile, thereby increasing the surface bearing pressure. 111

The experiment on blanket peat at Lon Mor, Inverness-shire, where the growth of Lodgepole pine and Sitka spruce is being studied in relation to water-table depth, continues. As previously reported, the upper horizons of the peat are much drier under Lodgepole pine than under the natural wet heath vegetation, subjected to the same ground water treatment, and studies have progressed to determine the effects of this permanently reduced moisture condition on the physical properties of the peat. Not only have moisture retention capacities been reduced, but the permeability to water of the top 10 cm has been more than doubled. The combined effect of these two factors may, in the long term, adversely affect the establishment of subsequent crops. 110

The growing demand and current shortage of peat of a relatively low degree of decomposition for horticultural use has focused attention on the need to further assess the suitability of more highly humified types abundantly available in Scotland. As the quality of peat for horticultural purposes is not wholly dependent on its botanical origin and other inherent characteristics, studies have been initiated to evaluate the effects of production and other processes on the physical properties of the end product. In collaboration with the Department of Plant Physiology, experiments are still in progress to investigate factors which influence the occurrence of blossom-end rot in tomatoes in peat substrates[11]. 114, 408

Nutrient Uptake from Forest Soils

Study of the uptake and cycling of nutrients in crops of Sitka spruce continues. At four of the six experimental sites, both the tree crop and the soil organic layers have been resampled following completion of five years monitoring of nutrient movement in litter fall and rainwater. Only two experiments now remain in this first, intensive, stage of the study. While many samples have still to be analysed, the limited results presently available from this study, together with those from an earlier investigation on Corsican pine, are already providing a useful insight into the mechanisms that enable trees to thrive on poor acid soils. Models of the input and cycling of nutrients[12, 13] suggest that once canopy closure occurs, and cycles of nutrients within the ecosystem have been established, the input of potassium and magnesium in rainwater and atmospheric aerosols is sufficient to maintain healthy growth, even if there is no uptake of these nutrients from the soil. Similarly, the input of calcium and nitrogen from atmospheric sources may be significant, although unlikely to match the demands of the tree, but the input of phosphorus is always far from adequate. Consideration of these processes has led to the suggestion that there are three distinct nutritional stages in the life of a coniferous forest[14] (i) an establishment phase during which nutrient demand rises to its maximum as the canopy is formed, (ii) a subsequent phase after canopy closure when the only net immobilisation is in structural tissue and humus, and nutrient demand is, therefore, less pronounced, and (iii) a late rotation stage when excessive immobilization of nitrogen in the humus may lead to site deterioration and nitrogen deficiency. During stage (ii), the input and retention of atmospheric nutrients is at its most effective, and fertilizer applications are likely to have only a limited effect on growth. Nitrogen application at stage (iii) may be very rewarding, as would the application of any limiting nutrient at stage (i). Indeed, in many respects, the most valuable role of fertilizers in forest management is this ability to reduce the time to canopy closure, since during this period the trees are most dependent on nutrient supply from the soil. 115, 116, 117

Nutrient inputs are only effective if they are retained in the forest. During the past year, an array of zero tension lysimeters and suction soil-water samplers have been installed at the Fetteresso experiment to measure leaching losses of natural inputs and of fertilizer-applied nutrients. In addition, yields tables[15] have been prepared giving values for nutrient removal in harvested pine, according to growth rate and age, both for conventional harvesting of stems alone and for various possible intensive harvesting policies involving removal of crown components or stumps traditionally left on site. These results show that nutrient removal, even by fairly intensive harvesting, is unlikely to exceed the known input for most nutrients, the particular exception again being phosphorus for which removal in even conventional harvesting is well in excess of known atmospheric inputs and will have to be compensated by weathering of soil minerals.
115, 117

The search for improved methods of diagnosing nutrient deficiencies has continued, as has the nutrient advisory service provided to forest nurseries on the basis of soil analysis carried out by the Department of Soil Fertility. Reviews have been prepared of the evolution and present practice of peatland forestry in Britain.[16,17]. 117

Input of Chemical Elements from the Atmosphere

Greater emphasis is being given to the study of atmospheric inputs, in relation both to the input of nutrients to plant communities that have to depend on this source of supply, and to the concommitant input of pollutants, particularly sulphur, that may have an effect on plant growth, pedogenesis and the quality of stream-water. Trees provide a convenient crop for such experimentation and initial work has concentrated on developing the necessary conceptual framework[18] and appropriate methodology[19,20]. Preliminary results have been published of the input of sulphur and other elements in rainwater at various sites across Scotland and[21,22] of the relationship of this input to the cycle of sulphur within the ecosystem. 115

Nitrogen Mineralization in Peat and Mor Humus

Investigation of factors that influence the rate of release of mineral nitrogen in organic soils has continued, emphasis being given to the effects of afforestation with Lodgepole pine. Analyses of samples from six sites in the North of Scotland have shown that the marked drying of the peat beneath trees is accompanied by changes in the pattern of mineral nitrogen production, measured in laboratory incubation experiments, and by decreases in pH and base saturation. Samples from beneath the trees showed lower rates of CO_2 accumulation and higher rates of mineral nitrogen production than those from adjacent unplanted areas. This suggests that the microbial population in planted peat tends to immobilize less mineral nitrogen, thus increasing the amount potentially available to the plants[23]. Experiments using samples from a blanket bog site at Naver Forest, Sutherland, have shown that the magnitude of these changes is related to the depth of the peat and the extent of drying. In general, the effects of afforestation are most marked in peats between 1 m and 3 m deep. These investigations are being extended to include Sitka spruce, pine, birch and semi-natural vegetation on peaty gley soils at Falstone forest, Northumbria. 111, 116, 5701, 5703

In a joint study with the Department of Microbiology, samples of peat have been taken from the controlled water-table experiment at Lon Mor, Inverness-shire. Levels of ammonium-nitrogen in the surface layers (0-200 mm) show a pronounced seasonal pattern, rising from a minimum in winter to a maximum in summer when the influence of water-table depth is most pronounced. A small-scale experiment using peat cores has been initiated to study the effects of lime and PK fertilizers on the microbial population and amounts of inorganic nitrogen present. 110, 116, 503

Studies on the forms and rates of release of mineral nitrogen from forest organic layers under fertilized Scots pine have continued at Culbin (Laigh of Moray forest). As part of a glasshouse experiment designed to test the response of Sitka spruce to NPK fertilizers, the effects of the treatments on nitrogen mineralization in the growth medium, a mixture of forest floor material from beneath pole-stage Sitka, are being studied. 115, 116, 117

A collaborative study with the Forestry Commission (Site Studies North) on the chemical composition of peat from a variety of bog types has established useful relationships between site characteristics, as defined by vegetational factors, and the nutrient status of the peat[24]. 111

References:

1. Peat. By P. D. Hulme, A. T. Nicol and R. A. Robertson. To appear in Memoirs of the Soil Survey of Great Britain: *Soils of the country round Stranraer and Wigtown* by C. J. Bown and R. E. F. Heslop, Macaulay Institute for Soil Research.

2. Peatland classification with special reference to Scotland. By P. D. Hulme *Proc. Int. Symp. on Classification of Peat and Peatlands*, 76-81, Hyytiälä, Finland, 1979. International Peat Society, Helsinki.

3. The classification of Scottish peatlands. By P. D. Hulme. To appear in *Scottish Geog. Mag.*

4. Remote sensing in peat-resource and land-use survey. By G. C. Stove and R. A. Robertson, *ARC Res. Rev.*, **5**, 21-27, 1979.

5. Application of remote sensing to peat survey. By R. A. Robertson and G. C. Stove, in *Profitable Use of our Land Resources*, 48-49. (Edited by N. Tomter), The Scottish Peat and Land Development Association, 1979.

6. Improving our image. By G. C. Stove and R. A. Robertson, in *The High Frontier*. (Edited by R. Low), The Third Eye Centre (Glasgow) Ltd., 1979.

7. Peat resource mapping in Lewis using remote sensing techniques and automated cartography. By G. C. Stove and P. D. Hulme. To appear in *Proc. 5th Annual Conf. of the Remote Sensing Society*, Durham, 1978.

8. *Calliergon richardsonii* (mitt.) Kindb, from the late-Devensian of Lang Lochs mire, Shetland. By P. D. Hulme, *J. Bryol.*, **10**, 281-285, 1979.

9. A contribution to the phytogeography of Scotland. By P. D. Hulme and S. E. Durno. To appear in *New Phytol.*

10. An investigation of peat at the Slochd Pass Inverness-shire. By S. E. Durno and A .T. Nicol. Submitted to *Trans. Bot. Soc. Edinb.*

11. Blossom-end rot in tomatoes. By P. C. DeKock, A. Hall, R. H. E. Inkson, J. M. Cooper, J. D. Miller and R. A. Robertson, *J. Sci. Fd. Agric.*, **30**, 508-514, 1979.

12. Nutrient cycles in pine and their adaptation to poor soils. By H. G. Miller and O. J. L. Pauline, *Can. J. Forest Research*, **9**, 19-26, 1979.

13. The nutrient budgets of even-aged forests. By H. G. Miller. To appear in The Ecology of Even-aged Forest Plantations, *Proc. Meeting of Div. I, IUFRO, Edinburgh,* 1978.

14. Nutrient cycles in relation to tree growth and soil development. By H. G. Miller. To appear in *Proc. Welsh Soils Discussion Group,* 1979.

15. Biomass and nutrient accumulation at different growth rates in thinned plantations of Corsican Pine. By H. G. Miller, J. D. Miller and J. M. Cooper. To appear in *Forestry.*

16. Peatland forestry in Scotland. By H. G. Miller and R. A. Robertson, in *Profitable Use of our Land Resources,* 44-47. (Edited by N. Tomter), The Scottish Peat and Land Development Association, 1979.

17. Peatland forestry in Britain: its evolution and present practice. By H. G. Miller and R. A. Robertson. To appear in *TELMA, Berichte der Deutschen Gesselschaft für Moor-und Torfkunde.*

18. Definitions and concepts. By H. G. Miller, M. H. Unsworth (University of Nottingham) and D. Fowler (Institute of Terrestrial Ecology), in *Methods for Studying Acid Precipitation in Forest Ecosystems,* 4-9. (Edited by I. A. Nicholson, I. S. Paterson and F. T. Last, Institute of Terrestrial Ecology and UNESCO, 1979), Record of Edinburgh Workshop, 1977.

19. Throughfall, stemflow, crown leaching and wet deposition: Chairman's report and recommendations. By H. G. Miller, in *Methods for Studying Acid Precipitation in Forest Ecosystems,* 59-75. (Edited by I. A. Nicholson, I. S. Paterson and F. T. Last, Institute of Terrestrial Ecology and UNESCO, 1979), Record of Edinburgh Workshop, 1977.

20. Assessing the contribution of crown-leaching to the element content of rainwater beneath trees. By K. H. Lakhani (Monk's Wood Experimental Station) and H. G. Miller. To appear in *Effects of Acid Precipitation on Terrestrial Ecosystems.* Edited by T. C. Hutchinson, New York, Plenum Press.

21. Sulphur content and acidity of rainwater at six rural sites across Scotland. By H. G. Miller and J. D. Miller, in *Proc. Int. Symposium Sulphur Emissions and the Environment,* 77-80, London, 1979. The Society of Chemical Industry, Water and Environment Group, 1979.

22. Changes in sulphur content and acidity of rainwater on passing through the canopy of Sitka spruce forest. By H. G. Miller, J. D. Miller and J. M. Cooper, in *Proc. Int. Symposium on Sulphur Emissions and the Environment,* London, 1979, 225-227. The Society of Chemical Industries, Water and the Environment Group, 1979.

23. Some effects of afforestation with Lodgepole pine on rates of nitrogen mineralisation in peat. By B. L. Williams, J. M. Cooper and D. G. Pyatt (Forestry Commission Northern Research Station). To appear in *Forestry.*

24. Peatland classification for forestry in Great Britain. By D. G. Pyatt (Forestry Commission Northern Research Station) and B. L. Williams, in *Proc. Int. Symp. on Classification of Peat and Peatlands,* 351-366, Hyytiälä, Finland, 1979. International Peat Society, Helsinki.

3. SPECTROCHEMISTRY

R. O. Scott

The work of the department has continued along lines similar to those described in previous reports and can be divided into three interrelated categories: the investigation of the distribution of trace elements in soils, soil profiles and plant materials; the examination of the composition and structure of the inorganic and organic components of soils; and the provision of an analytical service for the determination of trace elements in samples supplied by other departments. To improve the latter facility a Perkin Elmer Model 560 atomic absorption/emission spectrometer which incorporates a facility for the direct read-out of element concentration has been installed. A Varian Techtron Model 65 Hydride Generator has been donated to the department by the manufacturers for application development. This should enable the quantitative determination of metalloids, such as arsenic, antimony and bismuth, for which methods have hitherto been lacking, to be carried out.

Trace Elements in Soils, Plants and Biological Materials

During the year there has been a much greater demand than in previous years by the Department of Soil Fertility for the determination of the total amounts of trace elements in soils with regard to possible environmental contamination. Such problems have arisen, for example, from the application to land of sewage sludges with high metal contents and of distillery wastes containing large amounts of copper, the reclamation of sites used for municipal waste disposal and occurrence of cattle poisoning. 5205

A review of the occurrence and the forms of trace elements in soils and of their importance to the health of plants and animals, along with methods of analysis, has been published[1] and a paper on trace elements in soils and plants is still awaiting publication[2]. The biosignificance and analysis of trace elements in agricultural soils was reviewed by the Director when he gave the First Tom Miller Memorial Lecture at the North of Scotland College of Agriculture on 3rd May. The lecture is to be published by the College[3].

Soils and Soil Parent Materials. The investigations into the value, as a soil extractant, of the naturally occurring chelating agent 2-ketogluconic acid, mentioned last year, have continued and a paper reporting this work is in preparation. 201, 502

The determination of trace elements in selected soil profiles sampled by the Department of Soil Survey has continued. Work on soils from the areas covered by Sheet 84 (Nairn and Cromarty) and Sheets 40 and parts of 41 and 32 (Kinross, Elie and Edinburgh) have been completed. Work on soils from the areas covered by Sheets 117 to 122 (Orkney) and Sheets 43 and 44 (Isle of Mull) is in progress. A study of the variability in the total contents of eight trace elements in the C horizon samples of 59 soil profiles of the Ettrick Association has been carried out. The results indicate that in the area covered by soils of this association, the total contents of cobalt, gallium, nickel, titanium and vanadium are significantly lower in samples from the north-east than from the south-west. A paper on the distribution of the total and acetic acid-extractable lead in over 200 soil samples from 41 profiles, sampled by the Department of Soil Survey, has now been published[4]. 101, 201, 703

Descriptions of the work carried out in collaboration with the Department of Pedology on the origin and significance of extractable titanium and vanadium in Scottish podzols[5] and on the mineralogy and heavy metal content of some serpentine soils in north-east Scotland[6] have also been published. 104, 201

A paper reporting the contents of 62 elements in 10 surface soils derived from a wide range of parent materials has been published[7]. The average soil contents for most elements are similar to published values for crustal abundances and considerable information has been obtained on the contents of several elements, including arsenic, the halides, niobium, the rare earths, tungsten and uranium, for which hitherto little information has been available. The results of this investigation have confirmed that the total trace element content of the Scottish soils examined is mainly a function of the geological nature of the parent material from which the soil was derived. 201, 205

As a result of the interest in the possible association of certain trace metals with organic accumulations, the composition of some New Zealand coals has been investigated in collaboration with R. Soong, a visiting research worker, and the results have been submitted for publication[8]. 204

In collaboration with the Department of Soil Organic Chemistry, investigations into the origin of organic-metal complexes in soils and their behaviour during the process of podzolization have been reported[9]. 201, 203, 307

Soil Status and Plant Uptake. A description of the sources contributing to the trace element content of soils, such as the parent material, the application of fertilizers, sewage sludges, fly ash, etc., and atmospheric deposition, along with factors affecting their availability and plant uptake, has been published[10]. 201, 202

In collaboration with the Department of Soil Fertility, the results from a number of long-term field experiments on the effects of various rates of fertilizer applications, especially that of nitrogen, on the trace element contents in mixed herbage, have now been reported[11]. Also in collaboration with the above Department, the examination of the effects of applying distillery waste over a period of at least 50 years (Ann. Rept. No. 46, 1975/76) on the total and EDTA-extractable contents of copper in the soil and on the uptake by various crops, has continued[12]. The results of the above experiment are described in fuller detail in the report of the Department of Soil Fertility. 201, 202, 609

In collaboration with the Department of Soil Organic Chemistry, laboratory and pot experiments are being carried out to study the effects of adding increasing amounts of peat, containing a low content of copper, to a soil heavily contaminated with copper by disposal of distillery waste. The effects of these treatments on the extractable levels of copper in the soil and on the copper uptake by plants are being examined. 201, 202, 307

Analysis of soils and plants from the long-term sewage sludge experiments at the ADAS Experimental Horticulture Stations has continued. Plot soils at Luddington which had been treated at high rates of application with five different sewage sludges, have now been analysed for their water-extractable contents. As an example, to illustrate the relative amounts extracted by different reagents, in one treatment the zinc contents extracted by acetic acid, EDTA, ammonium acetate and water were 190, 170, 40 and 1·7 mg per kg respectively. On the evidence available, the amounts extracted from the soil by ammonium acetate or water show a slightly poorer relationship with the zinc contents of timothy grass, than those extracted by acetic acid or EDTA. At the Lee Valley site, the amounts of zinc and copper extracted by aqua-regia from top soils sampled in 1972 and 1977 were almost identical, indicating that there had been little or no loss of these elements over this period. The trace element contents of mixed herbage sampled at this site in 1977, confirmed the findings reported previously for Luddington (Ann. Rept. No. 48, 1977/78), that sludge-treatment resulted in enhanced levels of copper, nickel and zinc, but not chromium in the plants. The zinc content of the rye grass separated from the mixed herbage showed an approximately linear relationship with the amount of zinc extracted from the soil by either acetic acid or EDTA, as had been found previously for timothy grass at Luddington (Ann. Rept. No. 47, 1976/77). The zinc content of clover, on the other hand, did not show a similar relationship; the clover content followed the extractable content of zinc in the soil only at the lower levels of zinc and appeared to approach a limiting value of about 200 mg Zn per kg of plant dry matter at the higher levels. Some of these findings have now been published[10] and a paper reporting work carried out on samples from the Luddington experiment is still awaiting publication[13]. 201, 202

Miscellaneous materials examined during the year include samples of chalk for the University of Aberdeen; eucalyptus leaves for a British zoo; tree-leaves for Doncaster Metropolitan Borough Council; conifer needles for the Forestry Commission, Surrey; cabbage for the National Vegetable Research Station, Wellesbourne; and grass for the Department of Agricultural Research, Botswana. Support has also been given to the Rowett Research Institute, Aberdeen, by analyzing many samples of herbage and animals diets, mainly in connection with their experiments on cobalt deficient ruminants. 5205, 5206

Spectrochemical Methods of Analysis

No changes have been made during the year either in the arc emission methods employed for the determination of trace elements or in the techniques for their pre-concentration prior to analysis. A description of the techniques in use for the determination of trace elements in soils and plants has been submitted for publication[14]. Two papers by the Director and his former colleagues at Imperial College on non-dispersive atomic fluorescence spectroscopy[15] and the determination of palladium by electrothermal atomization[16] have been published. 205, 206

As mentioned in last year's report, the use of aqua-regia digestion for both uncontaminated and sewage sludge-treated soils, followed by atomic absorption analysis, has been investigated to find if this could be a suitable alternative to semi-quantitative arc emission analysis for assessing the soil status, in terms of the total amounts of metals present. In uncontaminated topsoils derived from a wide range of parent materials, aqua-regia digestion removed about 70 per cent of the total copper, and 60 per cent of the manganese and zinc, but the cadmium was present in amounts too low to be determined. Higher amounts were removed from sludge-treated soils; 80 per cent of the total copper and zinc, 70 per cent of the manganese and 90 per cent of the cadmium. These recoveries, however, are probably adequate for assessing the degree of metal contamination which could arise from the application of sewage sludge to land. Full recoveries were obtained only when the ignited sample was digested with hydrochloric acid under pressure in a closed PTFE bomb, but the apparatus and technique is likely to be both too expensive and time-consuming to permit it being used for the routine monitoring of potentially toxic metals. The papers mentioned in the previous Report on thermostatted electrodeless discharge lamps for atomic spectroscopy[17] and recent developments in atomic fluorescence spectroscopy[18] have now been published, as have the papers on early contributions by British atomic spectroscopists[19] and practical developments in atomic-fluorescence spectroscopy[20], but that on general aspects of atomic spectrochemical analysis in soil research still awaits publication[21]. 205, 206

Flame techniques; Emission and Atomic Absorption. Some changes in instrumentation have been made, partly to provide high-temperature flame determination of calcium in soil extracts and partly to replace progressively the ageing Varian Techtron AA4 atomic absorption spectrometer. To these ends the laboratory-built 3-channel flame photometer employed for the determination of calcium, potassium and sodium has been taken out of commission, although still in working order, after some 25 years in operation and some one-and-a-half-million element analyses. Calcium, magnesium and sodium determinations of soil extracts are now being performed using the laboratory-built 3-channel atomic absorption/emission flame spectrometer described in last year's report. This uses a twin-nebulizer burner assembly to provide a high-temperature nitrous oxide-air-acetylene flame. Ionization supression is provided continuously by using one nebulizer to aspirate a solution containing 500 mg per litre of potassium while the other, fitted with a branched nebulizer, supplies the sample and the strontium buffering solutions. This eliminates the time-consuming operation of adding the spectroscopic buffers to the sample solutions before analysis and allows the sample solution to be analysed directly. No interferences are observed from the aluminium or phorphorus present in the samples over the concentration ranges of these elements which occur in soil extracts or solutions of plant ashes. A description of this instrument is in preparation. 206

The analyses of EDTA and other types of soil extracts for copper, managanese, zinc, and cadmium by atomic absorption, together with the determination of potassium by emission, have been transferred from the Instrumentation Laboratory IL 751 to a recently installed Perkin Elmer Model 560 atomic absorption/emission spectrometer. The burner of this latter instrument has proved particularly free of the slot-clogging problems experienced with most other burner types after prolonged nebulzation of 0·05M EDTA extracts of soils. This transfer of analyses from the IL 751 spectrometer will now permit it to be used for development work on electrothermal atomization methods. 206

Partly as a result of the reorganisation described above, but mainly because of the difficulty of retaining trained assistant scientific officer staff in the competitive technical labour market in Aberdeen, the number of determinations of calcium, sodium, potassium, cobalt, copper, manganese and zinc carried out as a service to other departments of the Institute, has shown a slight fall this year. Determinations of magnesium, on the other hand, have increased by about 30 per cent. The number of specialized analytical problems dealt with during the year by atomic absorption methods in response to the Institute's research requirements and requests from other organisations, has increased considerably. These have included the determination of low iron contents in culture media (for the Department of Soil Organic Chemistry), aluminium, silicon and other elements in microbial digests of labradorite (for the Department of Microbiology) and in ammonium oxalate extracts of soils (for the Department of Pedology), mercury in blood (for Health and Safety at Work), nickel in chicken diets (for the Moredun Institute, Edinburgh), nickel in accumulator plants (for the University of Florence, Italy) and lead in fish flour (for the Marine Laboratory, Aberdeen). 5206

The development of "atom-trapping" as a means of concentrating elements, for example, copper, has continued and an account of some of this work has been published[22]. A chapter on AAS and AES has been submitted[23] and an instrumental modification for the IL751 spectrometer published[24]. 206

Microwave Plasma Emission. The development of a method for the determination of nitrogen isotope ratios by molecular emission has continued and a preliminary report has now been published[25]. Recent work has shown that tubes filled with ammonia can be used without the inclusion of an inert carrier gas, such as argon, and the most suitable operating conditions have now been established. Cooling one end of the discharge tube to $-60\,^{\circ}C$ has enabled determinations to be made below 0·1 atom per cent of ^{15}N using the (1, 0) band-head of N_2 at 316 nm. The method is being applied to materials from nitrogen-fixation studies supplied by the Department of Microbiology and from studies on the plant uptake of different forms of nitrogen for the Department of Plant Physiology. 206, 408, 514

Radiofrequency Plasma Emission. The original 28 mm Greenfield type plasma torch has been replaced by a 21 mm Fassel torch and the generator re-tuned to accommodate the lower inductance of the smaller coil. Extensive analytical studies have been carried out on Mo. Whilst the sensitivity is good with a detection limit *ca.* 2 $ng.ml^{-1}$, interferences are encountered in the presence of easily ionizable matrix elements. Studies are currently in progress to determine the cause of these interferences. The original one-piece quartz plasma torch is being replaced by a torch fabricated from boron nitride which can be machined to accurately reproducible dimensions. This torch also features a novel gas introduction design and improved flow characteristics. Preliminary work has commenced on the selection of analytical lines suitable for use with the inductively coupled plasma in association with a multi-channel direct reading spectrometer. 205, 206

Laser Spectroscopy. The preliminary testing of the remote sensing system being developed from equipment supplied by the Royal Society, the Science Research Council and the Agricultural Research Council has been completed. The full system has been assembled and used for sulphur dioxide measurements in a test cell. *In situ* measurements have not yet been possible because of stray light effects encountered in the receiving telescope. These are being reduced by the incorporation of baffles into the optical system. Further development of the microcomputer control system has been undertaken to permit experimental results to be graphically displayed on a teletype or visual display unit. This work was the subject of a thesis for which the PhD degree of the University of Aberdeen was awarded[26, 27].

Other Methods of Trace Element Analysis

Cathodic Stripping Voltammetry. A description of the method for the determination of selenium in soils and plants by differential pulse cathode-stripping voltammetry worked out conjointly with the Department of Soil Fertility, and reported last year, has now been published[28].

Spark Source Mass Spectrometry. The study of the comprehensive elemental content of a group of surface soils derived from a wide range of parent materials mentioned in last year's report has now been published[7], as has the account of interferences and their correction in the determination of the rare earth elements in soils and rocks[29]. 201, 205

Various samples of soils, soil profiles, rocks, animal diets, plants biological materials and standard reference materials including rocks, sediments and sludges have been analyzed by spark source mass spectrometry (SSMS) in the course of the year. 5205

The development of three convergent lines of research aimed at facilitating the quantitative spark source mass spectrometric analysis of biological materials has been the principal concern this year. The first of these was a comprehensive investigation of interferences and of the effects on analytical sensitivity, produced by the likely matrix components of ashes of biological (and other) materials. In these investigations simulated ashes formulated from powder mixtures of pure components such as Al_2O_3,

$CaCO_3$, K_2CO_3, K_2SO_4, KH_2PO_4, MgO, NaCl, Na_2CO_3 and SiO_2 were employed. The spectra of each of these individual compounds have been used to identify the interfering species produced with both aluminium and carbon conducting matrices. Effects on sensitivity were studied by analysing standard samples of each of these compounds containing 20 trace-elements. Although only general conclusions can be drawn here, the sensitivities for all elements vary significantly with major changes in the sample matrix whether the conducting material is aluminium or carbon. Carbon-based sample electrodes provide higher sensitivity for most elements than those based on aluminium conducting material but in carbon the interferences are more numerous and difficult to understand[30]. For this reason aluminium conducting material is preferred for the comprehensive analysis of complex samples. In view of these matrix effects the synthetic standard samples, required for quantitative analysis of biological materials because of the paucity of suitable authenticated reference materials, will need to be based on matrices similar in composition to those of the samples being analyzed. 205

The second problem relevant to the analysis of biological materials of animal origin proved to be the difficulty in dry-ashing them at 450°C. Although milled plant materials can be ashed at 450° effectively by this technique, animal tissues, such as liver, provided ashes containing about 30 per cent carbon. For SSMS analyses such ashes are unsatisfactory in view both of the influence of carbon on SSMS sensitivity and of its complex interferences effects. Treatment with nitric acid before and after dry ashing was not satisfactory while commonly used ashing aids such as MgO or $Mg(NO_3)_2$ were undesirable for analysis because they introduced large amounts of the multi-isotopic element magnesium with increased possibilities for superpositional molecular ion interferences. Powdered Al_2O_3 as an ashing aid for materials such as liver, however, produced at 450°C, in one operation, free-running powdered ashes with less than one per cent carbon. The use of Al_2O_3, readily prepared from pure aluminium metal, is convenient for SSMS analysis in which the aluminium is used as the conducting material since it introduces no additional matrix element. The effect of Al_2O_3 on the losses of the metalloids, such as As and Se, in the ashing process is being investigated. The addition of Al_2O_3 does, however, introduce a dilution factor. 205

The third area of research, with implications for the analysis of both biological materials and other types of samples, is concerned with the development of preconcentration and separation techniques for trace analysis by SSMS. Such techniques not only enable elements to be determined whose abundance in natural samples is too low for direct SSMS analysis (gold, platinum, and noble metals) but can also remove interfering elements and provide the trace element concentrated in a matrix of constant major element composition irrespective of the sample type. Considerable progress has been made in the developmnt of a cementation preconcentration technique in which the trace elements in solution are passed through a column of aluminium powder on which the elements are cemented by spontaneous electro-chemical deposition. The dried aluminium powder with its collected trace elements can be made into an electrode and analyzed directly by SSMS. Quantitative recovery of copper, gold, lead and silver has already been demonstrated and in suitably treated columns As, Os, Pd, Pt, Rh, Sb, Se, Sn, Te, and Tl are substantially recovered. The technique is in the final stages of optimization and a preliminary report has been submitted for publication[31]. Tentative applications have shown that it is possible to determine gold, for example, in soil digests. Its application to other elements is being investigated, but it does not appear to be applicable to the transition elements. 205

Molecular Spectrometry of Soil Constituents

Optical Absorption Spectrometry. Collaborative work with the Departments of Soil Organic Chemistry and Microbiology have continued along several lines. Soil polysaccharide has been more fully characterized by a combination of infrared spectroscopy and GC-mass spectrometry, leading to a better understanding of its functional groups and their reactivities, the sugar units present and how these are linked in the polymer[32]. 208, 305

The black melanin pigment present in the sclerotial rind of the plant pathogen *Sclerotinia sclerotiorum* has been isolated and an insight into some of its structural features has been obtained from chemical analysis, methylation and IR studies. Based on the results from these techniques a novel proposal has been put forward, that conjugated strongly hydrogen-bonded carboxyl groups contribute significantly to the characteristic IR absorption band of melanin at 1615 cm^{-1}. It is further suggested that the low N content ($<1\%$) indicates that the melanin structure may be similar to that of oxidized polymerized catechol[32]. Because of its insolubility and general intractibility, melanin should persist in soil, probably in the humin fraction of the organic matter. Attempts are being made to isolate this fraction from a variety of soils to test this proposal, and to determine its composition, structural features and contributions to soil properties such as cation exchange. 208, 301, 507

Comparative studies are being made on other dark fungal pigments which have been isolated from several sources including *Aspergillus niger* and *Rhizoctonia solani.* Unlike that from *S. sclerotiorum* these pigments are soluble in alkali and their IR spectra closely resemble those of soil humic and fulvic acids, and also to some extent those of synthetic oxidised catechol polymers. A green water-soluble pigment produced by resting spores of *A. niger* is also being investigated. Of considerable interest is the observation that oxalic acid, identified by its IR spectrum, is also released in substantial amounts by the resting spores. 208, 301, 507

Although the acidic fraction of water-soluble soil organic matter (fulvic acid) is of great importance in cation exchange and metal binding reactions in soil, its structure is still unresolved. The controversy centres on the relative importance of aromatic and aliphatic units. It was previously shown (Ann. Rept. No. 46, 1975/76) that the predominantly aliphatic polymaleic acid appeared to be a good model for the natural fulvic acid, and efforts to quantify the proportion of aromatic structures in fulvic acid are now being made by applying pyrolysis-mass spectrometry, IR and UV spectrophotometry. 108, 208, 304, 305

The experience gained from the characterization by IR spectroscopy of the surfaces of synthetic goethite (Ann. Rept. No. 46, 1975/76, No. 47, 1976/77) has been applied to ferrihydrite, a poorly-ordered hydrated iron oxide, which may be more widespread in soils than was hitherto thought. It has been shown that contrary to the accepted structure of this mineral, there are hydroxyl groups on its surfaces and also, more surprisingly, within its structure, which is thought to resemble that of akaganéite, β-FeOOH[33]. Natural ferrihydrates always contain silicate, and the possibility that this anion might be adsorbed on the ferrihydrite surface is being investigated. Papers have now been published on the use of infrared spectroscopy in the investigation of oxidation-reduction reactions of structural iron in smectites such as nontronite[35], to study the interaction between alkali metal hydroxides and structural hydroxyl groups in ferruginous smectites[36] and to reassign the space group of boehmite[37]. 207

Several lines of collaborative work with the Department of Mineral Soils on weathering studies have continued. In one, which also involves the Department of Microbiology, IR spectroscopy has assisted X-ray diffraction in identifying oxalates formed by the action of lichens on underlying rocks. In another investigation on the weathering of granite, IR has provided proof that an iron-rich weathering product consists of a unique platy form of hematite with a distinct spectrum resembling that of the kidney-ore form of this mineral. The product, however, is not pure hematite, but appears to be a hybrid of hematite and the recently discovered ferruginous analogue of pyrophyllite. 104, 207, 508

In addition to their intrinsic value in characterizing and identifying soil constituents, these studies help to broaden the base of IR experience upon which the correct interpretation of spectra depends. Such a goal is difficult to achieve even for the expert but, for the non-expert, failure to recognize the origin of absorption bands due to unexpected components or contaminants is only too common. The consequent misinterpretations can give rise to erroneous conclusions about structure and composition, two instances of which, involving both organic matters and minerals, have been recognized and corrected[38, 39]. 207, 208

The synthesis of imogolite is now covered by a patent[40], but work to define more precisely the conditions under which it can form continues[41, 42, 43]. Proto-imogolite, a soluble hydroxy-aluminium orthosilicate complex that forms in acid solutions, appears to be an essential precursor of well-formed imogolite, and it has been argued that this complex must play a role in the pedogenesis of podzols and acid brown forest soils[44]. Proto-imogolite allophanes were first identified in Italian volcanic ash soils[45] but are probably an important form of reactive aluminium in the B horizons of temperate acidic leached soils. Attention is now turning to characterizing the properties of imogolite, and clear evidence has been obtained for molecular sieving action, based on the 1 nm pores in its tubular structure[46]. Reviews of the applications of IR spectroscopy to minerals and inorganic compounds[47, 48], and of the nature of water on soil particles[49] have now been published as has the proceedings of the 1978 International Clay Conference[50]. 207

Mössbauer Spectroscopy. In the area of soils and clay mineral research, papers have been published on the spectra of chlorites and their decomposition products[51], a combined infrared and Mössbauer study of reduced nontronites[34], the characterization of iron oxides in soils[52], and a combined electron paramagnetic resonance and Mössbauer study of iron-rich impurities in montmorillonites[53]. In addition to these, the applications of Mössbauer spectroscopy in soil research were reviewed in an invited lecture to The Chemical Society Mössbauer Discussion Group and a series of seven lectures on the use of Mössbauer spectroscopy in soils and clay minerals research were presented at a NATO Advanced Studies Institute. This latter group of lectures is currently being prepared for publication. 104, 203, 207

The work in collaboration with the Department of Soil Organic Chemistry on the effect of pH on the reaction between iron and humic acid in aqueous media has now been published[54] and a further paper on the nature and origin of organic-metal complexes of soil is awaiting publication[9]. 203, 307

There have been few project developments during this year. However, a detailed investigation of the iron-containing components in some bauxites has been initiated along with a study of the nature of the iron in some purified kaolinites. 203

Electron Paramagnetic Resonance (EPR) Spectroscopy. In collaboration with the Department of Soil Organic Chemistry, papers have been published on the uptake of the metal ions Cu(II) and Mn(II) by wheat roots[55, 56] and lectures on the use of EPR spectroscopy in the study of micro-nutrient uptake by plants were presented at an international conference on electron spin resonance of transition metal ions in inorganic and biological systems. Further work in this field of metal ion uptake by plants has been carried out this year, particularly with Cu(II) and VO(II) ions. 203, 309

Investigations have begun on samples of dried plant materials with a view to comparing their spectra with those from soil organic matter and to characterizing some of the metal complexes occurring in them. 203, 307

Also in collaboration with the Departments of Soil Organic Chemistry and Microbiology the free radicals present in, and derived from, various soil organic matter fractions and fungal extracts have been further investigated. 203, 304, 307, 512

Further work on the characterization of metal complexes with amino acids as a function of concentration and pH has been carried out and extended to include some dipeptide complexes. Computer programs have been developed which enable the spectra of samples to be simulated both in solution and in the solid state. Part of this work was presented at an international conference on electron spin resonance on transition metal ions in inorganic and biological systems. 203

References:

1. Trace element distribution. By T. S. West, *Educ. Chem.*, **16**, 62-65, 1979.
2. Trace elements in soils and crops. By R. L. Mitchell and J. C. Burridge. To appear in *Phil, Trans, Roy, Soc., London.*
3. Biosignificance and analysis of trace elements in agricultural soils. By T. S. West. *First T. B. Miller Memorial Lecture.* North of Scotland College of Agriculture. Submitted for publication.
4. The lead content of the soils of the Wigtownshire area of Scotland. By G. A. Reaves and M. L. Berrow, *J. Sci. Fd Agric.*, **30**, 1-7, 1979.
5. Origin of extractable titanium and vanadium in the A horizons of Scottish podzols. By M. L. Berrow, M. J. Wilson and G. A. Reaves, *Geoderma*, **21**, 89-103, 1978.
6. The mineralogy and heavy metal content of some serpentinite soils in north-east Scotland. By M. J. Wilson and M. L. Berrow, *Chem. Erde*, **37**, 181-205, 1978.
7. The total trace element content of some Scottish soils by spark source mass spectrometry. By A. M. Ure, J. R. Bacon, M. L. Berrow and J. J. Watt, *Geoderma*, **22**, 1-23, 1979.
8. Studies of mineral matter in some New Zealand coals. Part II. Major and trace elements in some New Zealand coal ashes. By R. Soong and M. L. Berrow. To appear in *N.Z. J. Sci.*
9. The nature and origin of organic-metal complexes of soil. By M. V. Cheshire, M. L. Berrow, B. A. Goodman and C. M. Mundie. To appear in *Proc. Conf. Migration Organo-Minérales dans les Sols Témpéres*, Nancy, 1979.
10. Sources and distribution of trace elements in soils and related crops. By M. L. Berrow and J. C. Burridge, in *Proc. Conf. Management and Control of Heavy Metals in the Environment*, London (1979), 304-311, 1979.
11. Effect of NPK fertilizers on trace element uptake by herbage. By J. W. S. Reith, J. C. Burridge and M. L. Berrow. To appear in *J. Sci. Fd Agric.*
12. Effects of copper in distillery wastes on soils and plants. By J. W. S. Reith, M. L. Berrow and J. C. Burridge, in *Proc. Conf. Management and Control of Heavy Metals in the Environment*, London (1979), 537-540, 1979.
13. Trace element levels in soils: effect of sewage sludge. By M. L. Berrow and J. C. Burridge. To appear in *Tech. Bull. Min. Agric, Fish and Fd., Proc. Conf. Inorganic Pollut. Agric.*, 1977.
14. Spectrochemical determination of trace elements of agricultural interest. By R. O. Scott. To appear in *Proc. XXI Coll. Spectros. Internat.*, Cambridge, 1979.
15. Non-dispersive atomic fluorescence spectrometry with a carbon filament atom-reservoir. By M. Hargreaves, A. F. King, J. D. Norris, A. Sanz-Medel and T. S. West, *Anal. Chim. Acta*, **104**, 85-92, 1979.
16. The atomic absorption spectrometric determination of palladium with a carbon-filament electrothermal atomizer. By E. A. Bound, J. D. Norris, A. Sanz-Medel and T. S. West, *Anal. Chim. Acta*, **104**, 385-387, 1979.
17. Thermostatted electrodeless discharge lamps in atomic spectroscopy. By D. F. Bartley, T. Hurst, J. D. Norris and T. S. West, *Rev. Anal, Chem.*, **4**, 19-59, 1978.
18. Some recent developments in atomic fluorescence spectroscopy. By T. S. West. *Pure. Appl. Chem.* **50**, 837-843, 1978.
19. Some early British contributions to atomic spectroscopy (1672-1885). By T. S. West, *Proc. Anal. Div. Chem. Soc.*, **14**, 177-179, 1977.
20. Practical developments in atomic fluorescence spectroscopy. By T. S. West, *Proc. Anal. Div. Chem. Soc.*, **13**, 266-271, 1976.
21. Atomic spectrochemical analysis in soil science research. By T. S. West. To appear in *Proc. Euroanalysis III Conf.* Dublin, 1978.
22. An investigation of atom collection phenomena in atomic absorption spectrometry of copper. By J. Khalighie, A. M. Ure and T. S. West, *Anal. Chim. Acta*, **107**, 191-200, 1979.
23. Atomic Absorption and Flame Emission Spectrometry. By A. M. Ure. To appear in "*Modern Instrumental Techniques in Soil Analysis.*" Ed. K. A. Smith, Marcel Dekker.

24. Improved precision by servo-mechanical stabilization of cyanogen band emission in a nitrous oxide/acetylene flame. By A. A. Verbeek and A. M. Ure, *Anal. Chim. Acta*, **102**, 195-199, 1978.

25. A simple procedure for ^{15}N determination in relatively large samples by emission spectrometry. By J. C. Burridge and I. J. Hewitt, *Commun. Soil Sci. Plant. Anal.*, **9**, 865-872, 1978.

26. A dye laser differential absorption system for the measurement of atmospheric sulphur dioxide. By A. R. Morrison, PhD Thesis, University of Aberdeen.

27. A microprocessor-controlled laser remote sensing system. By A. R. Morrison and B. L. Sharp, *Proc. Anal. Div. Chem. Soc.*, **16**, 23-25, 1978.

28. Determination of selenium in soils and plants by differential pulse cathodic-stripping voltammetry. By S. Forbes, G. P. Bound and T. S. West, *Talanta*, **26**, 473-477, 1979.

29. The correction of interference effects in the determination of the rare earth elements and hafnium by spark source mass spectrometry. By J. R. Bacon and A. M. Ure, *Anal. Chim. Acta*, **105**, 163-176, 1979.

30. Matrix effects and interferences in the spark source mass spectrometry of non-conducting powders of agricultural interest. By J. R. Bacon and A. M. Ure. To appear in *Advances in Mass Spectrometry*, Vol. 8.

31. Concentration procedures for trace element analysis by spark source mass spectrometry. By Karen H. Welch and A. M. Ure. To appear in *Proc. Anal. Div. Chem. Soc.*

32. Structural studies on soil polysaccharide. By M. V. Cheshire, J. M. Bracewell, C. M. Mundie, G. W. Robertson, J. D. Russell and A. R. Fraser, *J. Soil Sci.*, **30**, 315-326, 1979.

33. A preliminary study of fungal melanin by infrared spectroscopy. By J. D. Russell, D. Jones, D. Vaughan and A. R. Fraser. Submitted to *Geoderma*.

34. Infrered spectroscopy of ferrihydrite: evidence for the presence of structural hydroxyl groups. By J. D. Russell, *Clay Minerals*, **14**, 109-114, 1979.

35. Infrered and Mössbauer studies of reduced nontronites. By J. D. Russell, B. A. Goodman and A. R. Fraser, *Clays Clay Miner.*, **27**, 63-71, 1979.

36. An infrared spectroscopic study of the interaction of nontronite and ferruginous montmorillonites with alkali metal hydroxides. By J. D. Russell, *Clay Minerals*, **14**, 127-137, 1979.

37. Lattice vibrations of boehmite (γ-A1OOH): evidence of a C_{2v}^{12} rather than a D_{2h}^{17} space group. By J. D. Russell, V. C. Farmer and D. G. Lewis, *Spectrochim. Acta*, **34A**, 1151-1153, 1978.

38. A re-interpretation of the IR spectrum of sewage sludge fulvic acid. By J. D. Russell. Submitted to *Soil Sci. Soc. Am. J.*

39. On spurious absorption bands in IR spectra of clay minerals. By J. D. Russell. Submitted to *Clay Minerals*.

40. Synthetic Imogolite. Inventor, V. C. Farmer, U.S.P. 4152404.

41. The stability, free energy, and heat of formation of imogolite. By V. C. Farmer, B. F. L. Smith and J. M. Tait, *Clay Min.*, **14**, 103-107, 1979.

42. Characterisation of the chemical structures of natural and synthetic alumino-silicate gels and sols by infrared spectroscopy. By V. C. Farmer, A. R. Fraser and J. M. Tait, *Geochim, Cosmochim. Acta*, **43**, 1417-1420, 1979.

43. Synthetic imogolite, a tubular hydroxyaluminium silicate. By V. C. Farmer and A. R. Fraser, in *International Clay Conference, 1978*. 547-553. Eds. M. M. Mortland and V. C. Farmer. Elsevier, Holland, 1979.

44. Possible roles of a mobile hydroxyaluminium orthosilicate complex (proto-imogolite) and other hydroxyaluminium and hydroxyiron species in podzolization. By V. C. Farmer. To appear in "*Migrations Organo-minérales dans les Sols Témpéres,*" C.N.R.S. International Colloquium, Nancy, 1979.

45. Imogolite and proto-imogolite in an Italian soil developed on volcanic ash. By V. C. Farmer, A. R. Fraser, J. M. Tait, F. Palmieri (University of Naples, Italy), P. Violante (University of Naples, Italy), M. Nakai (Ehime University, Japan) and N. Yoshinaga (Ehime University, Japan), *Clay Miner.*, **13**, 271-274, 1978.

46. Gas chromatography absorption studies on synthetic imogolite. By M. J. Adams. To appear in *J. Chromatography*.

47. Infrared spectroscopy in mineral and inorganic chemistry. By V. C. Farmer, in *Sixth Ceramic Chemists Conference* (on Silicate Analysis), 101-102. Spec. Publ. 98, Brit. Ceram. Res. Assoc., 1979.

48. The role of infrared spectroscopy in a soil research institute. Characterization of inorganic materials. By V. C. Farmer, *European Spectroscopy News,* **25**, 25-27, 1979.

49. Water on particle surfaces. By V. C. Farmer, in *The Chemistry of Soil Constituents.* Edited by D. J. Greenland and M. H. B. Hayes, 405-448, Wiley, Chichester, 1978.

50. *International Clay Conference 1978.* (Edited by M. M. Mortland and V. C. Farmer), Elsevier: Holland, 1979.

51. Mössbauer spectra of chlorites and their decomposition products. By B. A. Goodman and D. C. Bain, *International Clay Conference,* Oxford, 1978. (Editors M. M. Mortland and V. C. Farmer), Developments in Sedimentology, **27**, 65-74, 1979.

52. Application of Mössbauer spectroscopy to the study of iron oxides in some red and yellow/brown soil samples from New Zealand. By C. W. Childs, B. A. Goodman and G. J. Churchman, *International Clay Conference,* Oxford, 1978. (Editors M. M. Mortland and V. C. Farmer), Developments in Sedimentology, **27**, 555-565, 1979.

53. An investigation by Mössbauer and electron paramagnetic resonance spectroscopy of the possible presence of iron-rich impurity phases in some montmorillonites. By B. A. Goodman, *Clay Minerals,* **13**, 351-356, 1978.

54. A Mössbauer spectroscopic study of the effect on pH on the reaction between iron and humic acid in aqueous media. By B. A. Goodman and M. V. Cheshire, *J. Soil Sci.,* **30**, 85-91, 1979.

55. An electron paramagnetic resonance study of the uptake of Mn(II) and Cu(II) by wheat roots. By B. A. Goodman and D. J. Linehan, in *The Soil-Root Interface.* 67-82, (Editors J. L. Hartley and R. Scott Russell), 1979. Academic Press.

56. An electron paramagnetic resonance study of the uptake of copper(II) by wheat roots. By B. A. Goodman, D. J. Linehan and H. J. K. Powell, in *Proc, 2nd New Zealand Seminar on Trace Elements and Health,* 63-70. (Editors J. Aggett, T. Kjellstrom and D. Crowe), University of Auckland, 1979.

4. SOIL ORGANIC CHEMISTRY

G. Anderson

Investigations have continued into the nature of the organic components in soils, their distribution in different soil types and the effects that they have on plant growth. When organic matter humifies in the soil, large amounts of it are converted into brown amorphous polymers known as humic substances. Much of the department's work is concerned with these polymers, their chemical nature, their origins and their influence on nutrient availability and uptake. Other polymers being studied are the polysaccharides which make up about one-tenth of the organic matter and play an important part in keeping the soil in a good physical condition. Organic compounds containing the nutrient elements nitrogen, phosphorus and sulphur, and compounds having physiological effects on plant growth, are also under investigation. A paper has been published outlining the nature of soil organic matter and the methods that are used in its analysis[1].

The department's analytical facilities have been strengthened during the year by the installation of an "Altex" high-performance liquid chormatograph. This is equipped with a versatile microprocessor-controlled solvent programming system which allows complex solvent mixtures to be used in a reproducible manner. An instrument for analysing the elemental composition of compounds eluted from a gas chromatograph has also been assembled. The gaseous components pass into a microwave helium plasma and the emission from the element to be analysed is measured at an appropriate wavelength in a monochromator. It is intended initially for the analysis of carbon, nitrogen, hydrogen and oxygen and is being further developed to provide nitrogen isotope analysis using procedures devised at NIRD.

Soil Polysacchride

Attention has been focused on the way in which individual plant polysaccharide components decompose in the soil. Experiments were first carried out using ^{14}C-labelled cereal rye straw to test a method for measuring the glucose that occurs in the form of cellulose[2]. The straw was then incubated with soil and the rates of decomposition of the cellulose-glucose and of the total xylose were examined by a number of mathematical models. It was found that the decomposition of both components could be described by the same mathematical expression and that a minor part of both, around 35%, was decomposed very rapidly[3]. The stabilisation of the remainder, assuming that initially it is just as susceptible to attack, may have several causes such as a decrease in the supply of available nitrogen to the attacking microorganisms, gradual humification of the molecules, or sorption on colloids. A similar pattern of decomposition has been found with fresh ryegrass[4]. In co-operation with the Department of Microbiology the influence of soil fauna, including earthworms, on the progress of decomposition of plant material is now being studied. 305, 512, 701, 5613

A comparison is being made of the decomposition of plant residues in the rhizosphere with that in the remainder of the soil. Preliminary studies with grass residues indicate that their polysaccharide components decompose more slowly in the rhizosphere of barley plants than in soil alone. The reason is not yet clear, but one possibility is that the continuous supply of root exudate lessens the demand by microorganisms for alternative organic sources. 305, 512, 5613

Studies have continued on the nature of the polysaccharide synthesized by various miroorganisms in soil. It has proved difficult to establish monocultures of some bacteria in soil sterilized by irradiation or by autoclaving, but this has not been the case with yeasts or filamentous fungi.
305, 512, 5613

A joint paper with the Department of Microbiology on the effects of soil drying and storage on subsequent microbial growth has been published[5].

When carbohydrates are analysed by pyrolysis—mass spectrometry, furfural derivatives are among the products invariably detected. Fractionation on columns of the adsorbent " Polyclar " is used to separate polysaccharide, which is not adsorbed, from other polymers in the soil fulvic acid, but it has now been found that the adsorbed polymers, also, release a large proportion of furfural on pyrolysis. This suggests a covalent linkage between remaining carbohydrate constituents and the more humified brown fulvic polymers, but the amount of furfural is greater than can be accounted for by the reducing sugar content of these polymers. The nature of this material is under investigation. 108, 305

A review article on soil polysaccharide[6] and a paper on its chemical structure[7] have now been published, and a paper on its origins has been accepted for publication[8].

Polymaleic Acid as a Soil Organic Model

The synthetic polymer polymaleic acid (PMA) has been separated into fractions of different molecular size by membrane ultrafiltration and, in collaboration with the Department of Mineral Soils the products have been examined by pyrolysis—gas chromatography. Although the degradation products are predominantly aliphatic, they include phenols and aromatic hydrocarbons and these are obtained in greatest amount from the higher molecular weight fractions. The presence of aromatic moieties in the larger molecules fractionated by gel chromatography has already been shown by the detection of benzene polycarboxylic acids after nitric acid oxidation.
108, 208, 303, 304

As noted in last year's report, PMA has proved to be very stable when incubated in soil. This has now been demonstrated for a number of agricultural surface soils and for a sandy podzolic B_h horizon. The stability was shown by polymers labelled with ^{14}C in either the methylene or carboxyl groups and their subsequent incorporation into humic substances is being examined. The polymer is initially water soluble, but soon requires acid extraction and subsequently can only be extracted with alkali. The higher molecular weight fractions of the polymer then tend to appear in the humic acid, and the smaller molecules in the acid soluble material and fulvic acid.

The effects of factors such as temperature and moisture level on the distribution within the various fractions of the soil organic matter are being studied further. 303, 304, 5613

A paper on the uptake of PMA by plants has now been published[9] and an investigation has been carried out on possible effects of PMA on the uptake of major ions from a nutrient solution by wheat seedlings. Under the conditions used there was no obvious effect on the uptake of potassium, sodium, calcium or chloride. In a number of experiments there was some increase in the uptake of phosphate, but this was not always the case and the experiments are being continued. 309

Soil Polycarboxylic Acids

Investigations have continued on the chemical properties of humic substances, particularly the nature of the compounds released during acid hydrolysis. Levulinic acid is one of the hydrolysis products and it known to be formed by acid hydrolysis of hexoses. In agreement with this, humic acid releases small amounts of levulinic acid which correspond well with the hexose content of the humic acid. In contrast, however, those fractions of the soil organic matter which resemble PMA release four to six times more levulinic acid than can be accounted for as hexose and even predominantly polysaccharide fractions show considerable discrepancies between the theoretical and actual yields. Possible sources of the levulinic acid, and succinic acid with which it is usually associated, are being examined. 108, 208, 304

An apparent discrepancy has also been noted (see section on Soil Polysaccharide) between the carbohydrate content of fulvic acid components isolated by adsorption on " Polyclar " and the amount of furfural derivatives detected during analysis by pyrolysis-mass spectrometry. 108, 305

If the soil polycarboxylates are derived from readily identifiable natural polymers such as lignin and polysaccharide then it is reasonable to assume that molecules with different degrees of oxidation will occur and that fractionation may be possible on this basis. Various techniques are being examined which do not involve the initial precipitation of humic acid by adding mineral acid to an alkaline extract. Instead, the addition of a hydrogen-saturated resin is known to produce the carboxylic acids and no precipitation then occurs even at pH3. The whole extract can subsequently be subjected to chromatographie or other separation techniques in either an acid or a salt form. 303, 304

A paper on the nature of the organic matter in the B horizon of podzols is awaiting publication[10]. 304

Organic Nitrogen and Sulphur

Studies on the fractionation of organic nitrogen have continued, in parallel with the experiments involving polycarboxylic acids. Further information has been obtained on the distribution of sulphur-containing amino acids in co-operation with the Department of Soil Fertility. 303, 602

Measurements of amino acids in plant materials have also been carried out for the Departments of Plant Physiology and Peat and Forest Soils.
115, 303, 401

A note has been published commenting on a recent paper describing the measurement of bacterial DNA in soils[11], but a review paper on organic phosphorus in soils is still awaiting publication[12].

Fungal Pigments

Studies have been continued, in collaboration with the Departments of Microbiology and Spectrochemistry, on the extraction and characterisation of some fungal pigments which are possible precursors of humic substances. The organisms *Rhizoctonia solani, Aspergillus niger* and *Coniothyrium minitans* produce pigments which are soluble in alkali and insoluble in acid and whose infra-red spectra and biological activities are similar to those of soil humic acids. In contrast, a pigment isolated from the sclerotial rind of *Sclerotinia sclerotiorum* is an acid and alkali-insoluble melanin of the catechol type, whose properties suggest it might accumulate in the humin fraction of the soil organic matter[13]. 208, 301, 507

The formation of the melanin pigment is likely to occur by the action of polyphenoloxidase on phenolic acids and appreciable amounts of the enzyme *o*-diphenoloxidase do indeed occur in the clear, viscous liquid exuded from the sclerotia prior to the darkening of the rind. A soil fumigant, Dazomet, both inhibits *o*-diphenoloxidase activity and prevents darkening of the sclerotial rind. The enzyme inhibition occurs by a mechanism which involves binding the copper required for activity in a Cu-S covalent bond and this was confirmed in tests with several chelating agents, substances containing thiol groups, cyanide and azide[14, 15]. Dazomet may also influence enzyme activities in agricultural crops and a paper on its effects on polyphenoloxidase activity in potato tubers has been submitted for publication[16]. 301, 311, 507

A technique has now been developed for obtaining the yellow-green pigment from spores of *A. niger* (Annual Report No. 45, 1974/75) in sufficient quantity for investigation of its nature and properties.
208, 301, 507

Metal Complexes of Humic Acid

A joint paper with the Department of Spectrochemistry on the nature and origin of the organic-metal complexes of soil is awaiting publication[17]. The distribution of radioactivity from ^{14}C-labelled barley plants in various organic matter fractions of the soil was determined immediately after mixing with the soil. The distribution of copper, iron, manganese and vanadium was also established, and the nature of the organic-metal complexes examined by electron paramagnetic resonance spectrometry.

A paper describing the effect of pH on the reaction between iron and humic acid has now appeared[18]. 201, 203, 307

Effects of Organic Matter on Micronutrient Availability to Plants

Work has continued on the organic components in soil which influence the availablity to plants of micronutrient cations. Uptake into plant roots occurs mainly from the soil solution where the cations may exist as free ions or are complexed by organic ligands. A paper describing the availability to plants of ferric iron complexed by synthetic or natural soil-derived ligands has now appeared[19]. The micronutrient cations in the soil solution are in equilibrium with those adsorbed on clays, hydrous metals oxides and insoluble organic matter. Nutrient-solution experiments on the uptake of iron, copper, zinc and manganese, adsorbed on hydrous iron and aluminium oxides, have shown that the iron and copper are unavailable to plants in the presence of even small amounts of the oxides, but become available when soil-derived organic ligands are in the solution. In contrast, adsorbed zinc and managanese, at low levels of the oxides, are taken up more freely by plants in the absence of the ligands than in their presence. On the other hand, at high levels of the oxides, the availablity of zinc, and possibly manganese, is increased by the presence of the ligands, as is the case with iron and copper. 309

A paper on the effects of humic acid on the uptake of iron by plants has been published[20]. 309

Effects of Organic Matter on Enzymes

Papers dealing with the effects of soil organic matter on the activity and synthesis of enzymes in plant roots have been published[21-27]. Studies are now being made of the effects of soil organic matter on soil enzymes such as invertase, amylase and phosphatase. It has been shown that humic and fulvic acids can enhance soil invertase activity by increasing the maximum velocity of the reaction without affecting the affinity of the enzyme for its substrate[28]. Inorganic phosphate will also enhance soil invertase activity, particularly in limed soils. This response apparently depends primarily on pH, but may also be influenced by soil type. However, it can also be affected by the treatment of the soil prior to assay. 311, 317

Work has continued in field plots on the effects of different cropping systems on the levels of several organic components and on the activities of a number of soil enzymes. Throughout the summer months invertase activity was highest in the fallow plots in contrast to the activities of amylase (sometimes used as an indicator of changes in the soil biomas) and phosphatase which were higher in the plots growing potatoes, peas and barley. The levels of water-soluble phenolic acids were also higher in the cropped plots, but so far no consistent differences have been detected between those under the different crops. However, when the cropped soils were incubated for up to three days with added phenolic acids as the sole carbon source there were distinct differences, with the greatest amylase activity and CO_2 production in the barley soils, less in the potato soils and least in the fallow. The soils also differed in their relative response to individual phenolic acids such as *p*-hydroxybenzoic acid and vanillic acid. 301, 311, 512

Effects of Light and Gravity on Plant Seedling Growth

A paper reporting an inhibitory effect of excess moisture on the development of mustard seedlings has been published[29]. Although radicle growth in the early stages of seedling development is retarded by excess moisture, radicle emergence (germination) is not and under conditions of high light intensity, normally inhibitory to mustard germination, wetness can promote germination. These experiments point to an interaction between light and moisture in seed germination, white light decreasing the water potential of the seed. This effect is especially evident at lower temperatures. 309

Papers referred to in last year's report dealing with the interaction of light and gravity on the regulation of root growth have now been published[30, 31] and investigations have continued into the nature of the effects. Attempts to correlate the exposure of roots to light with the production of abscisic acid in the root-cap have so far been inconclusive. 309

The effect of light quality on the root response has been investigated in collaboration with Dr J. W. Hart of the Department of Botany, University of Aberdeen. It has been shown that continuous blue, red and far-red irradiation affect the growth of cress seedling roots. The effects are qualitatively similar to that of white light, the most obvious being an increase in the rate of geotropic curvature of the root. At equal photon flux densities, blue was more effective than red and far-red least effective. Vertically growing roots were unaffected by the light treatments, but horizontally growing roots, unable to realign themselves with the force field, developed a corrugated appearance. Here, too, blue was the most effective treatment. The effects of blue and red light on the root georesponse can be further distinguished by interposing a period of darkness between irradiation and application of the geostimulus. The blue inhibition has a quicker decay time than the red and is only fully effective in promoting geocurvature if given at the same time as the geostimulus whereas the red inhibition can persist across an interval of darkness prior to geostimulus. These results suggest the functioning of dual photopathways with differing photoreceptors. Short periods (5 min) of irradiation with blue or red light also promote geocurvature as does continuous far-red irradiation, but there is no clear evidence of red/far-red reversibility in the response, suggesting that the contribution of phytochrome in its low-energy mode must be at best minimal. An account of this work has been submitted for publication[32]. 309

Evidence for the operation of two photosystems has also been obtained from a study of the effect of light quality on the growth of the cress seedling hypocotyl. In this study the geotropic response of the hypocotyl was used to observe the growth response to red and blue light, both of which were, in contrast to far-red radiation, inhibitory to growth. Blue light was more effective at retarding growth (and therefore geocurvature) when given with the geostimulus whereas red light was more effective when given prior to the geostimulus. These kinetically distinct effects of blue and red light on hypocotyl development again point to the likely operation of two photosystems. An account of this work has been submitted for publication[33]. 309

Other Physiological Investigations

Joint papers with the Department of Plant Physiology on the effects of the growth regulators abscisic acid and benzyladenine on the inorganic and organic composition of the duckweed *Lemna gibba*, and on the effect of galactose on its growth, have now been published[34, 35]. A further paper on the biochemistry of blossom-end rot in tomatoes has been accepted for publication[36]. 305, 311, 402

An investigation has begun into the effects of selenium ions on catalase activity in homogenates of *Lemna gibba.* 311, 401

References:

1. Soil organic chemistry. By G. Anderson, *Education in Chemistry,* **16**, 35-37, 1979.
2. Techniques used in the study of the decomposition of straw in soil. By M. V. Cheshire and C. M. Mundie. To appear in "*Straw decay and its effect on utilization and disposal.*" Edited by E. Grossbard. Published by Wiley.
3. The decomposition of straw in soil. By M. V. Cheshire, G. P. Sparling and R. H. E. Inkson. To appear in "*Straw decay and its effect on utilization and disposal.*" Edited by E. Grossbard. Published by Wiley.
4. Transformation of carbohydrate constituents of grass during decomposition in soil. By M. V. Cheshire, C. M. Mundie and H. Shepherd, *J. Sci. Fd Agric.,* **30**, 330, 1979.
5. Effects of soil drying and storage on subsequent microbial growth. By G. P. Sparling and M. V. Cheshire, *Soil Biol, Biochem.,* **11**, 317-319, 1969.
6. Polysaccharides in soils. By M. V. Cheshire, in *Encyclopedia of Earth Science Series, Volume XII Soil Science, Part I,* 390-396, 1979.
7. Structural studies on soil polysaccharide. By M. V. Cheshire, J. M. Bracewell, C. M. Mundie, G. W. Robertson, J. D. Russell and A. R. Fraser, *J. Soil Sci.,* **30**, 315-326, 1979.
8. Comparison of the contribution to soil organic matter fractions, particularly carbohydrates, made by plant residues and microbial products. By S. Murayama, M. V. Cheshire, C. M. Mundie, G. P. Sparling and H. Shepherd. To appear in *J. Sci. Fd Agric.*
9. The uptake by plants of polymaleic acid: a polycarboxylic acid structurally related to those of soil. By D. J. Linehan, *Pl. and Soil,* **50**, 625-632. 1978.
10. Spodic horizon humus. By H. A. Anderson. To be published by the Centre National de la Recherche Scientifique, Nancy, France.
11. Bacterial DNA in soil: comment on a paper by Torsvik and Goksoyr, 1978. By G. Anderson, *Soil Biol. Biochem.,* **11**, 213, 1979.
12. Assessing of organic phosphorus in soils. By G. Anderson. To appear in *Proc. Symp. Role of Phosphorus in Agriculture.* Alabama, 1976.
13. A preliminary study of fungal melanin by infrared spectroscopy. By J. D. Russell, D. Jones, D. Vaughan and A. R. Fraser. Submitted to *Geoderma.*
14. Effects of dazomet on phenolase activity in sclerotia of *Sclerotinia sclerotiorum.* By D. Vaughan and D. Jones, *J. exp. Bot.,* **30**, 751-758, 1979.
15. An *in vitro* effect of dazomet on phenolase activity in exudates of *Sclerotinia sclerotiorum.* By D. Vaughan, D. Jones and B. G. Ord. Submitted to *New Phytol.*
16. Some effects of dazomet on o-diphenoloxidase activity in homogenates of *Solanum tuberosum.* By D. Vaughan and B. G. Ord, *New Phytol.,* **83**, 361-364, 1979.
17. The nature and origin of organic-metal complexes of soil. By M. V. Cheshire, M. L. Berrow, B. A. Goodman and C. M. Mundie. To be published by the Centre National de la Recherche Scientifique, Nancy, France.
18. A Mössbauer spectroscopic study of the effect of pH on the reaction between iron and humic acid in aqueous media. By B. A. Goodman and M. V. Cheshire, *J. Soil Sci.,* **30**, 85-91, 1979.

19. A comparative study of the effects of natural and synthetic ligands on iron uptake by plants. By D. J. Linehan and H. Shepherd, *Pl. Soil*, **52**, 281-289, 1979.

20. Humic acid and iron uptake by plants. By D. J. Linehan, *Pl. Soil*, **50**, 663-670, 1978.

21. Effect of humic acid on invertase synthesis in roots of higher plants. By D. Vaughan and R. E. Malcolm, *Soil Biol. Biochem.*, **11**, 247-252, 1979.

22. Effect of soil organic matter on peroxidase activity in wheat roots. By D. Vaughan and R. E. Malcolm, *Soil Biol. Biochem.*, **11**, 57-63, 1979.

23. Effects of humic acid fractions on invertase activities in plant tissues. By R. E. Malcolm and D. Vaughan, *Soil Biol. Biochem.*, **11**, 65-72, 1979.

24. Humic substances and phosphatase activities in plant tissues. By R. E. Malcolm and D. Vaughan, *Soil Biol. Biochem.*, **11**, 253-259, 1979.

25. Comparative effects of soil organic matter fractions on phosphatase activities in wheat roots. By R. E. Malcolm and D. Vaughan, *Pl. Soil*, **51**, 117-126, 1979.

26. Soil organic matter and root surface enzymes in winter wheat. By D. Vaughan, in "*The root surface interface*," 439-440. Eds. J. L. Harley and R. Scott-Russell. Pub. Academic Press, 1979.

27. Effect of soil organic matter on some root surface enzymes of and uptakes into winter wheat. By D. Vaughan, B. G. Ord and R. E. Malcolm, *J. Exp. Bot.*, **29**, 1337-1344, 1978.

28. An effect of soil organic matter on invertase activity in soil. By D. Vaughan and B. G. Ord. To appear in *Soil Biol. Biochem.*

29. An inhibitory effect of excess moisture on the early developments of *Sinapis alba* L. seedlings. By I. R. MacDonald and D. C. Gordon, *Plant Cell and Environment*, **1**, 313-316, 1978.

30. The regulation of root growth in cress seedlings by light and gravity. By I. R. MacDonald and D. C. Gordon, *J. Exp. Bot.*, **29**, 1051-1058, 1978.

31. The effect of Chlorflurenol on geosensitivity and light inhibition of cress roots. By I. R. MacDonald and D. C. Gordon, *J. Exp. Bot.*, **30**, 65-70, 1979.

32. The influence of light on geotropism in cress roots. By J. W. Hart and I. R. MacDonald. To appear in *J. Exp. Bot.*

33. Photoregulation of hypocotyl growth: geotropic evidence for the operation of two photosystems. By J. W. Hart and I. R. MacDonald. To appear in *Plant Cell and Environment.*

34. Effect of abscisic acid and benzyladenine on the inorganic and organic composition of the duckweed, *Lemna gibba* L. By P. C. DeKock, D. Vaughan and A. Hall, *New Phytol.*, **81**, 505-511, 1978.

35. The effect of galactose on the growth of *Lemna*. By P. C. DeKock, M. V. Cheshire, C. M. Mundie and R. H. E. Inkson, *New Phytol.*, **82**, 679-685, 1979.

36. The biochemistry of blossom-end rot in tomatoes. By P. C. DeKock, D. Vaughan and B. G. Ord. To appear in *Physiol. Plant.*

5. PLANT PHYSIOLOGY

P. C. DeKock

Calcium Deficiency

Studies on Blossom-End Rot (BER) of tomatoes have continued and a detailed paper on the effects of the form of nitrogen, whether ammonium or nitrate, on BER incidence has been published[1]. Controversy still exists whether water regime has much to do with the problems and a series of experiments were conducted in peat bags or (in conjunction with the Department of Peat and Forest Soils) in larger tubs of peat. The form of nitrogen was varied and the peat bags were maintained at three water regimes—dry, moist or wet. Results showed that the ammonium-ion determined the appearance of BER and water regime had little effect, but in the large tubs, lowest BER incidence was obtained in the plants kept at 70% saturation whereas the plants kept at 50 or 60% saturation gave significantly higher BER counts. Analyses of the peats and evaluation of the results are still proceeding. Some of the petiolar material of last year's experiments was used for a study on iron and phosphorus which has now been published[2].

402, 401

Biochemical studies on the enzymes and constituent compounds involved in BER have been made over the past few years; these are now collated and prepared for publication. 402

The carrot crop was adversely affected by the very wet weather of last year, resulting in the appearance of cavity spot of such severity that whole crops were consigned to feeding livestock, and the local canning factories were closed. Again it was shown that it was the form of nitrogen which was affecting the composition of the carrot in such a way that calcium deficiency was induced. Water-logging of the soil resulted in loss of nitrate-nitrogen while ammonium-nitrogen remained. Thus a very significant difference could be demonstrated between soils which supported healthy carrots and soils in which most carrots showed cavity spot, by monitoring the nitrate ion. The healthy carrots gave a free nitrate test with diphenylamine in concentrated sulphuric acid, whereas the affected carrots did not; most of the nitrate ion was evidently located in the medulla with very little in the cortex. Moreover the differences in the mineral content between healthy and affected carrots are much the same as those for healthy and BER affected tomatoes. Bacterial involvement as a primary cause seems to be unlikely. This work has been presented for publication and will be reported at two future meetings. In collaboration with the North of Scotland College of Agriculture studies on Internal Browning of Brussels Sprouts indicate that it may be a similar problem to cavity spot or BER. Spraying experiments have been carried out using a number of nitrogen forms. An earlier study on calcium in relation to nitrate-metabolism has now been published[3].

402, 408

Plant Hormones

A study of the effects of the kinin, benzyladenine (BA), a growth promoter and abscisic acid (ABA), a retardant, on the growth rates and mineral composition of Lemna has been published[4]. The significance of these findings in relation to uptake of ions from the soil has been pointed out[5]. It also appears that disappearance and formation of starch is dependent upon the hormonal balance within the tissue and that stomatal function is adequately encompassed by the above findings. It is also possible that organisms such as crown gall bacteria cause changes in the mineral composition of the affected tissue which are in accordance with excessive kinin production. 402

Nickel

Professor Ornella Gambi-Vergnano of the University of Florence, Italy, spent some time in the department researching her work on mechanisms of nickel tolerance in plants. The biochemical characteristics of these plants have been compared with nickel-susceptible species, particular attention being paid to the amino acids, for which an autoanalyser has been utilised. This work is being evaluated and prepared for publication. A characteristic of the tissues is the low phosphorus content such that iron remains metabolically available even in the presence of high nickel concentrations. 401

Lemna

The study of galactose toxicity in Lemna has been published[6], and the work extended to glucosamine and galactosamine, both of which are considerably more toxic, bringing about rapid cessation of growth. The toxicity is very much reduced by glucose and it could be that toxicity of these substances is related to readily available acetyl groups. The acetyl derivatives N-acetyl glucosamine and N-acetyl galactosamine are now being evaluated. 402

Further work has been done on the effect of water stress on Lemna using sintered glass funnels which either contained tap water or a dilute nutrient solution. It was shown that mineral changes induced by increasing water tension were similar to those induced by increasing concentration of abscisic acid. Polyethylene Glycol has also been used to induce water stress, the findings being much the same for this medium.

Papers on the effect of soil pH on potato tuber composition[7] and on the peroxidase and catalase enzymes within the tuber[8] have been published. 402, 401

Ion Flux Studies

Initial work on the effects of the ionphore A 23187 on calcium fluxes in onion root segments was carried out by addition to the standard complete nutrient solution (pH 5·6) which was used in all earlier flux studies with this tissue, and which served as the control for these experiments. The major effect observed was the doubling of the transport of radioactively-labelled calcium to the xylem, as measured by leakage from the cut ends of the segments. This was interpreted as evidence for the view that calcium transport from root cortex to the stele is a passive process, since it was enhanced by an agent which is considered to do no more than increase the calcium permeability of the membranes en route. An account of this work[9] has been accepted for publication.

For work now in progress on this topic, solutions at pH 7, with and without magnesium, are being used, since A 23187 can also act as an ionophore for Mg^{2+}, and it exhibits its greatest affinity for divalent cations at neutral pH. Results are slow in coming to hand owing to the heavy demand for radioactive counting facilities now arising in the Institute, but it is expected that these experimental conditions will show larger effects of the ionophore on calcium fluxes than have hitherto been observed.

Examination of the effects of synthetic ionophores on potassium fluxes in onion root segments has continued. Following the observation that the polyether benzo-18-crown-6 had a deleterious effect on the membranes of cortical cell peranchyma, the Department of Molecular Structures, Rothamsted Experimental Station, kindly provided a sample of the higher order "crown" compound ditertiarybutyldibenzo-30-crown-10, which had previously been shown to be more effective by two orders of magnitude, than lower-order members of the series, in inducing K^+ uptake by rat liver mitochondria, the only test tissue previously employed. In onion root segments, over the concentration range 0·0001 mM to 0·1 mM, a log-linear relationship was found between increasing "crown" concentration and decreasing K^+ uptake, so that at the highest concentration of di-t-butyldibenzo-30-crown-10, K^+ uptake was about half the rate observed at the 0·0001 mM concentration of the polyether. 407

Ion Fluxes and Translocation in Seedlings

This is now the area of study for an ARC studentship taken up in the Department in October. The emphasis is on absorption of cations, particularly calcium. The programme envisaged covers uptake and efflux in the roots, transport to the xylem, translocation to the shoot and absorption by leaf tissue. In the first year, work has concentrated on the root processes. Cation fluxes and transport in root segments of wheat seedlings (exemplifying a monocotyledon) and, for comparison, seedlings of mung bean (a dicotyledon) have been characterised. The most recent experiments have tested the effect of the amino acid analogue DL-parafluorophenylalanine on ion fluxes at the cellular level, and on transport to the stele. The analogue is considered to be assimulated in the course of protein turnover, to produce "nonsense" protein in place of the molecules involved in active ion transport. The results show that transport of potassium to the stele of mung bean root segments is reduced by the analogue, and that K^+ efflux from the cortical cells is rather faster than in the controls. The effect of the analogue on calcium fluxes and transport in both wheat and mung bean is negative. These findings indicate that whereas K^+ uptake is an active process, interfered with by the analogue, Ca^{2+} transport is a passive process. 407

Calcium uptake and Translocation in Tomato Plants

Depression of calcium uptake and translocation in the presence of ammonium continued to be of interest as a causative factor in the occurrence of blossom-end rot. The effects of ammonium, as opposed to nitrate, on growth and nutrient balance are well known, although the causes of the observed effects are less well understood. To examine the causes further, particularly with respect to depressed divalent cation uptake, trans-root electrical potentials were measured (between exuding sap of the detopped plant and the root medium) for plants grown in complete nutrient solutions, varying only in the substitution of ammonium sulphate for sodium nitrate. In the presence of ammonium, the trans-root potential was reduced to a mean of -32 mV from the mean nitrate value of -56 mV, a not unexpected consequence of replacing a major component of active anion (NO_3^-) uptake by a major component of active cation (NH_4^+) absorption. The resulting reduction in the electrochemical diffusion gradient from the medium to the xylem sap reduced the driving force on Ca^{2+} and Mg^{2+} both of which enter the root only by passive means.

The use of sulphate to accompany ammonium and replace nitrate when altering the nitrogen source in the nutrient solution may well exacerbate the depression of divalent cation uptake observed in the presence of NH_4^+, as suggested by some short-term nitrogen-free ^{45}Ca uptake experiments on seedlings, in the presence of varying amounts of sulphate and other anions.

407, 402

References:

1. Blossom-end rot in tomatoes. By P. C. DeKock, A. Hall, R. H. E. Inkson and R. A. Robertson, *J. Sci. Fd Agric.*, **30**, 508-514, 1979.
2. Active iron in plant leaves. By P. C. DeKock, A. Hall and R. H. E. Inkson, *Ann. Bot.*, **43**, 737-740, 1979.
3. Nitrate reduction in plant leaves in relation to calcium. By P. C. DeKock, A. Hall, A. Naylor and R. H. E. Inkson, *6th Long Ashton Symp. Nitrogen Assimilation of Plants*, 1979.
4. The effect of abscisic acid and benzyladenine on the inorganic and organic composition of *Lemna*. By P. C. DeKock, D. Vaughan and A. Hall, *New Phytol.*, **81**, 505-511, 1978.
5. The role of abscisic acid in the metabolism of plant roots. By P. C. DeKock, in *The Soil-Root Interface*, 421, Eds. J. L. Harley and R. Scott-Russell, Academic Press, 1979.
6. The effect of galactose on the growth of *Lemna*. By P. C. DeKock, M. V. Cheshire, C. M. Mundie and R. H. E. Inkson, *New Phytol.*, 82, 679-685, 1979.
7. Nutrient distribution in the potato tuber in relation to soil pH. By P. C. DeKock, A. Hall and R. H. E. Inkson, *Ann. Bot.*, **43**, 299-304, 1979.
8. A study of peroxidase and catalase in the potato tuber. By P. C. DeKock, A. Hall and R. H. E. Inkson, *Ann. Bot.*, **43**, 295-298, 1979.
9. The effect of the ionophore A23187 on calcium fluxes in cortical cells and transport to the stele in roots of *Allium cepa* L. By A. E. S. Macklon and A. Sim, in "*Plant Membrane Transport*," p. 415. Eds. R. M. Spanswick, W. J. Lucas and J. Dainty. Elsevier: North Holland Biochemical Press, 1980.

6. MICROBIOLOGY

J. F. Darbyshire

The role of micro-organisms in the soil, particularly close to plant roots, is emphasised in the research programme of the department. Microbiological projects form the major part of research package 5 of the Institute. Recent progress is described briefly below. Four members of staff attended scientific meetings relevant to their research projects during the year and one member visited three universities in U.S.A.

Interrelationships of Plant Roots and Microbes

The acetylene reduction test has been used extensively to monitor nitrogen fixation in the rhizosphere of four barley and two wheat cultivars in a local soil low in nitrogen. It would appear that this well-known technique is not satisfactory for use with soil when the rate of nitrogen fixation is low. Accordingly, nitrogen—fixing bacteria associated with cereal roots were further studied in the simpler medium of perlite amended with nutrients. Golden Promise barley was inoculated with *Aztobacter beijerinckii*, a nitrogen-fixing bacterium frequently isolated from Scottish soils. No nitrogen fixation was detected until eight weeks after germination of this barley unless the medium was amended with glucose (1% w/v). These results suggest that nitrogen fixation in the rhizosphere of unamended soils is often limited by the absence of a suitable source of energy, e.g. carbohydrates, rather than for other reasons. The quantities of soluble reducing sugars and amino acids in root exudates from a range of cereals are being regularly estimated. 514

Previous work in the department (Annual Report 1975/76) was concerned with a nitrogen-fixing bacterium inside the roots of one strain of Canadian wheat. Existing stocks of this strain and three closely related strains have been increased considerably by growing several generations of wheat in the glasshouse without any cross pollination. In the near future it is hoped to study the relationships between the wheat strains and nitrogen-fixing bacteria in detail. In collaboration with the Department of Spectrochemistry, attempts are being made to estimate nitrogen fixation in the rhizosphere and the transfer of nitrogen to the cereal plant by the use of a ^{15}N dilution technique. The cereals will be labelled with ^{15}N and the amount of ^{14}N transferred to the plant from the nitrogen-fixing bacteria will be determined by emission and mass spectrometry. Perlite and not soil will be the medium used in these ^{15}N dilution experiments, because of non-gaseous ^{14}N present in soil.

Several methods of estimating the microbial biomass in soil have been investigated (CO_2 evolution, ATP content, enzyme assays, carbon mineralisation). These methods have been applied to rhizosphere soil and correlated with the presence of microbial substrates in root exudates.

512, 513

An account of glasshouse studies of the microbial populations and nitrogen status of the rhizosphere soil around the roots of spring barley, in collaboration with the Department of Soil Fertility and North of Scotland College of Agriculture, are in the press[1]. Amendments of aqueous ammonia to two local soils increased take-all disease in spring barley to a greater extent than nitrate. 513, 603

A study of the fungal decomposition of phenolic acids in soils has begun in collaboration with the Department of Soil Organic Chemistry. Some of these acids are present in root exudates. Using a kaolin aggregate method, important data on the ecology and physiology of fungi from soil, including the rhiozsphere around the roots of several crops, have been obtained. 508, 311

Fungi

Ultrastructure. *Volutella* sp., one of the fungi concerned with the degradation of phenolic acids, has been examined in the scanning electron microscope. Several preparative techniques were tested. The best preservation was obtained by cryo-fixation when no chemical fixatives were used. Freeze drying caused shrinkage of some morphological features, which are used in taxonomic studies. 508

Sclerotia. A joint paper with the Department of Soil Organic Chemistry describing the effects of the soil fumigant, Dazomet, on phenolase activity in relation to the formation of pigments in sclerotia has been published[2]. Another paper dealing with how dazomet effects phenolase activity in the exudates of *Sclerotinia sclerotiorum* has been submitted for publication[3]. 507, 301

Protozoa

Systematics. A description of the ultrastructure of a giant soil amoeba is in the press[4]. As a result of observations made with light and electron-microscopes, this amoeba was identified as *Arachnula impatiens.* Previously, (Annual Report 1977/78) this amoeba was found to attack spores of several fungi as well as many other soil microbes. 510

Organic Matter

Microbial decomposition and synthesis. The rate of decomposition of rye straw in soil was investigated in a collaborative study with the Department of Soil Organic Chemistry. It was found that there were two distinct rates of decomposition in the first year; an initial rapid rate followed by a much slower rate. This pattern of decomposition can be described by a double exponential curve. A paper describing these results is in the press[5]. Further work is in progress to refine the mathematical model and to investigate the rates of decomposition of different plant substrates under a variety of environmental conditions. 512, 305

The addition of readily decomposable organic matter to soil often increases the rate of breakdown of existing organic matter in soil. The effect of plant roots on organic matter decomposition was investigated by by growing barley plants in a soil labelled with ^{14}C. The appearance of $^{14}CO_2$ was used as an indication of decomposition of ^{14}C-labelled organic matter. When glucose or yeast extract was added to the soil, the decomposition of ^{14}C organic matter was increased, but the presence of living barley roots had the opposite effect. When the aerial parts of the barley plants were removed, the roots of these plants increased decomposition. Chemical analysis of the plants showed that very little of ^{14}C was translocated to the shoots but the roots were moderately labelled. 512, 305

Experiments are in progress to determine the effect of Enchytraeid worms on the rate of decomposition of plant material. 512, 305

Pigmented fungi are generally more resistant to microbial lysis than hyaline species and fungal melanin may accumulate in soil. The preliminary results of a joint study with the Departments of Spectrochemistry and Soil Organic Chemistry of fungal melanins by infra-red spectroscopy has been submitted for publication[6]. 507, 208, 301

The study of polysaccharides synthesised by a range of soil micro-organisms in sterilised soil amended with ^{14}C glucose has continued. A paper describing the growth of micro-organisms in glucose-amended soils, which had been previously dried and stored, has been published[7]. A paper comparing the distribution of ^{14}C-labelled sugars from different sources has been published[8]. 512, 305

Biological Weathering

A collaborative study with the Departments of Mineral Soils and Spectrochemistry has been initiated to determine the extent to which soil fungi and lichens are implicated in the weathering of soil minerals. Lichens consist of fungi and algae in a symbiotic relationship. Some lichens and fungi produce organic acids which can release plant nutrients from mineral particles in soil; other species colonise rock surfaces. Observations on the mycobiont of a crustose lichen, *Pertusaria corallina*, colonising basalt and the fungus, *Aspergillus niger*, isolated from soil, have been submitted for publication[9]. A note on this subject has already been published[10]. Scanning electron microscopy and electron probe micro-analysis have been extensively used in these studies. These techniques were discussed in a lecture given at the First International meeting on Botanical Microscopy at the University of York in July, and a series of electron micrographs illustrating certain features of this work were displayed in a poster session. An invited lecture on aspects of this study was also given at a meeting of the Plant Pathology and Mycology Group at the Royal Botanical Gardens at Edinburgh in May. 508, 104, 109, 207

References:

1. Ammonium and nitrate in the rhizosphere of spring barley, *Hordeum vulgare* L., and take-all disease. By J. F. Darbyshire, M. S. Davidson, N. M. Scott, G. P. Sparling and P. J. Shipton (North of Scotland College of Agriculture). To appear in *Soil Biol. Biochem.*
2. Effects of dazomet on phenolase activity in sclerotia of *Sclerotinia sclerotiorum*. By D. Vaughan and D. Jones, *J. Exp. Bot.*, **30**, 751-758, 1979.
3. An *in vitro* effect of dazomet on phenolase activity in exudates of *Sclerotinia sclerotiorum*. By D. Vaughan, D. Jones and B. G. Ord. Submitted to *New Phytol.*

4. *Arachnula impatiens* Cienk., a mycophagous giant amoeba from soil. By K. M. Old and J. F. Darbyshire. To appear in *Prostistologica.*

5. The decomposition of straw in soil. By M. V. Cheshire, G. P. Sparling and R. H. E. Inkson. To appear in *Straw Decay and its Effect on Utilization and Disposal.* London: J. Wiley.

6. A preliminary study of fungal melanin by infrared spectroscopy. By J. D. Russell, D. Jones, D. Vaughan and A. R. Fraser. Submitted to *Geoderma.*

7. Effects of soil drying and storage on subsequent microbial growth. By G. P. Sparling and M. V. Cheshire, *Soil Biol. Biochem.*, **11**, 317-319, 1979.

8. Comparison of the contribution to soil organic matter fractions, particularly carbohydrates, made by plant residues and microbial products. By S. Murayama, M. V. Cheshire, C. M. Mundie, G. P. Sparling and H. Shepherd. To appear in *J. Sci. Fd Agric.*

9. Weathering of a basalt by *Pertusaria corallina.* By D. Jones, M. J. Wilson and J. M. Tait. Submitted to *Lichenology.*

10. Lichen fungi and weathering of minerals: an electron microscope and X-ray micro-analysis study. By D. Jones and M. J. Wilson, *Proc. Roy, Micro. Soc.*, **14**, 226, 1979.

7. SOIL FERTILITY

E. G. WILLIAMS

Since this Report will be appearing during the year of the Institute's 50th anniversary, it is appropriate in the introduction to recapitulate somewhat more fully than usual the main features and underlying principles of the departmental objectives and activities, and in the subsequent reviews of specific topics to give brief indications of their origins and earlier development, as well as summarizing progress during the last year. Fuller accounts of these subjects will be available in due course in the Jubilee Monograph.

The research programme as a whole continues to be directly aimed at practical improvement of soil fertility, manurial practices and crop production through better understanding of soil-nutrient-crop relationships. Work has accordingly been continued in the following interrelated areas: (a) nutrient relationships, properties, management and productivity of selected contrasting soil series, (b) effects of fertilizers, soil conditions, husbandry practices, environmental factors and physiological characteristics on the growth, development and chemical composition of the main agricultural crops, and (c) development, calibration and practical application of laboratory methods for evaluating the acidity and nutrient status of soils for advisory purposes. The overall experimental approach is concurrent development and integration of field, pot culture and laboratory studies, covering physical as well as chemical relationships, soil acidity and trace elements as well as major nutrients, interactions and toxicities as well as deficiencies, and longer term as well as immediate effects. During the last 30 years especially, the programme as a whole has been systematically geared to contrasting soil series, chosen in consultation with the Department of Soil Survey. In addition to providing essential quantitative information about the agricultural characteristics and performance of the different series, especially the nature, influences and amelioration of constraints on crop production, this approach enables the contrasting behaviour of the different soils to be used as a major aid to identification and measurement of the soil properties and processes which regulate nutrient supply and crop growth, and which underly effects of pedological factors, particularly differences in parent material and drainage status. The fertility programme is accordingly designed to be the quantitative complement to, and extension of, the broader qualitative characterization of soil series provided by the Soil Survey. Blanket coverage of all intermediate soil series, especially those of limited extent and practical importance, is not, however, envisaged. On the contrary, quantification of the pivotal soil factors governing the behaviour of contrasting series should enable the findings to be extrapolated to others without full experimental coverage, as well as contributing to the wider ultimate objective of better understanding of the behaviour of soils in general. Due attention is paid to the significance of soil constituents, but the emphasis is on the properties and field performance of the soil as a whole. By greatly extending the range of fertilizer and other soil treatments which can be examined, and providing fuller control over all growth factors, the pot culture programme provides an essential link between the field and laboratory studies. The final answers to practical questions of soil management and crop production must, of course, be referred to the field, and virtually all the laboratory studies are based on documented soil and crop samples from the field and pot culture programmes, thereby ensuring that the potential practical implications of the results can be more effectively considered.

To promote continual effective filtering of experimental findings into practice, the soil fertility programme has from the foundation of the Institute been closely allied with advisory soil testing in collaboration with the North of Scotland College of Agriculture, and with related consultative responsibilities. Together, these activities have formed, and continue to provide, an unique reciprocal link between research and practice, which not only ensures virtually automatic practical application of relevant results, but also fulfils the equally important function of drawing attention to practical problems which require experimental investigation. Over the years, the advisory soil testing work, details of which are given later, has undoubtedly made crucial contributions to efficient use of lime and fertilizers and to the major improvements which have taken place in the lime and nutrient status of agricultral land. Apart from essential discussions with Agricultural Advisory Officers concerning lime, fertilizer and trace element matters including interpretation of advisory soil reports, the main features of the other consultative activities continue to be participation in various meetings and demonstrations, mostly organized by the Scottish Colleges of Agriculture, and representation on technical committees. Recent examples under the former head include a Study Conference on Trace Elements in the Diets of Farm Animals, held in Aberdeen under the auspices of the Council of the Scottish Agricultural Colleges (COSAC), a discussion in Edinburgh on Land Assessment, organized by the Royal Scottish Geographical Society, and two meetings, one of the Scottish Arable Crops Group and the other on Farming to Beat Inflation, organized by the East of Scotland College of Agriculture. Further consultations have also taken place with the Department of Agriculture and Fisheries for Scotland (DAFS) and the three Agricultural Colleges to finalize Codes of Practice, required by the 1974 Control of Pollution Act, to cover application of Lime and Fertilizers for Arable Crops and Grassland and use of Livestock Manures on Agricultural Land. Representation has also been maintained on three other DAFS bodies, namely, the Scottish Standing Committee for the Calculation of the Residual Values of Fertilizers and Feeding Stuffs, the Consultative Committee for the Development of Spectrographic Work, and the Working Group on the Disposal of Sewage Sludge on Agricultral Land.

The department has currently two PhD students, Miss E. B.-I. Glass, an M.O.D. Research Student working on the use of piezoelectric crystals to measure atmospheric ammonia, under the supervision of the Director and Dr T. E. Edmonds, and Mr S. D. Young, an A.R.C. Research Student working on interactions of aluminium with soil organic matter, under the supervision of Dr B. W. Bache. It has also been a particular pleasure during the year to welcome, under the exchange scheme between the Royal Society and the Chinese Academy of Sciences, Mr Pu Guo-gan, Department of

Chemistry, Hofei University (People's Republic of China) who is collaborating with the Director and Dr Edmonds in work on electrochemical methods of analysis. Developments in this field have also been enhanced by the appointment of Dr S. Cooke, following successful completion of a piezoelectric PhD programme, to succeed Dr G. P. Bound. Part of Dr Cooke's work for the PhD degree has been published conjointly with the Director[1].

In the development of the department over the years, the aim has been to assemble an integrated soil fertility team of senior research officers with complementary interlocking expertise in the fields of soil chemistry (physical, organic, inorganic and analytical), agronomy and crop physiology, plant nutrition and plant chemistry, and soil physics. As indicated by the topic titles below, this objective has now been largely achieved, and to promote close coordination and efficient harnessing of the different disciplines progress has been made in planning a number of long-term field experiment centres into which they will all be integrated.

Normal contacts and collaboration have been continued with other research organizations, especially the Rowett Research Institute, and with other departments of the Institute, especially the Department of Soil Survey in relation to field experiment and advisory work, the Department of Statistics in the planning of experiments and processing of results, the Department of Spectrochemistry in trace element studies, and the Department of Soil Organic Chemistry concerning organic aspects of nutrient relationships in soils.

Fertilizer Requirements of Crops

Field experiments and supporting soil and crop analyses have from the outset provided the main foundations for both research and advisory activities. As already mentioned, the laboratory projects are largely based on documented soil and crop samples from field centres on different soil series. Similarly, formulations of general lime and fertilizer recommendations for different soils and crops, and calibrations of advisory soil tests to enable these to be adjusted to suit individual fields, are made possible by the quantitative field measurements of crop responses to incremental lime and nutrient dressings. Following extensive experimentation during the period of about 1950 to 1970, the trend during the subsequent years has been increasingly towards more detailed field studies at fewer centres. To cater for changes in the nature and composition of commercial fertilizers and in crop cultivars and cultural practices, however, there is continuing need to extend and update information on the effects of forms, rates, times, frequencies and methods of application of fertilizers on the yields and mineral composition of crops. Due attention has also to be given to implications of agricultural and economic factors, and to cover influences of seasonal variations it is necessary to continue different categories of experiments over a number of years. 601, 603, 608, 609, 5206, 5701, 5703

Fertilizer Placement for Swedish Turnips. This crop has maintained a high level of importance in north Scotland and in recent years has attracted renewed interest. As described in the last two Reports, two series of trials were, therefore, started in 1975, and have now been completed, each totalling 10 experiments, to reassess the effectiveness of fertilizers broadcast on the cutivated land before ridging compared with dressings placed in a narrow band 5 cm directly below the seed. More particularly it was necessary to determine whether current commercial fertilizers based on ammonium nitrate and ammonium phosphate can be more safely placed directly below the seed than the older mixtures based on ammonium sulphate and ordinary superphosphate, which were used in the earlier placement work. Although the summer rainfall in 1978 was somewhat below average, the crops established satisfactorily and the band placement had no adverse effects on germination and growth. The results from the 1978 experiments, three testing ammonium nitrate (Nitro-chalk) and three using NPK fertilizers, were in good agreemnt with the preceding trials in 1975-77. The main conclusion from the series of 10 experiments with Nitro-chalk is that, at rates of 50 and 100 kg N/ha, placement gives practically the same yields as broadcasting, whereas at 150 kg N/ha, a higher rate than would normally be recommended for swedes, placement frequently gives slightly lower yields. As with ammonium sulphate, therefore, no increase in effectiveness should normally be expected from placement of Nitro-chalk alone, but the safe upper limit is at least 100 kg N/ha and about twice as high as for ammonium sulphate. This greater latitude is advantageous in relation to placement of NPK mixtures. On phosphate deficient soils, placement of soluble phosphate can be expected to give two- to three-fold increases in its efficiency. With NPK mixtures based on ammonium sulphate, however, the earlier work showed that at higher rates of application this benefit was largely or entirely lost, due to negative effects from placing the ammonium sulphate component. The much greater tolerance to placement of ammonium nitrate should accordingly enable current NPK mixtures to be placed at correspondingly higher rates without impairing the benefits from placement of the soluble phosphate component. The second series of 10 experiments has fully confirmed this expectation. A granular fertilizer with an $N:P_2O_5:K_2O$ ration of 1:1:1 was placed at rates supplying 25, 37·5 and 50 kg P/ha and compared with a normal turnip fertilizer with a ratio of 1:2:1, broadcast at rates supplying 50, 75 and 100 kg P/ha. The corresponding treatments of the two fertilizers accordingly supplied virtually the same amounts of N and K, whereas the placed treatments supplied only half as much P as the broadcast dressings. As expected, placement of 25 and 37·5 kg P/ha in bands directly below the seed gave at least as good yields as from double these amounts broadcast. For example, in the five most responsive experiments, where very satisfactory yields of at least 70 t/ha were attained, 25 kg P/ha placed produced about 6 t/ha more roots than from 50 kg P broadcast. The gain from placement, of course, decreased with increasing P rate, but the yields from 37·5 kg P placed was still 3 t more than from 75 kg broadcast. As already mentioned for Nitro-chalk alone, however, placement of high N rates becomes inferior to broadcasting and with NPK fertilizers this tendency can be expected to be enhanced to some extent by the additional soluble salt provided by the potassium chloride component. In keeping with this, the placed NPK treatment supplying 50 kg P/ha, accompanied by 115 kg N and 95 kg K, gave 3 t less crop than from the corresponding broadcast application of 100 kg P. The latter dressing, however, is much above the normal recommended rate of about 65 kg P, and the current ammonium nitrate and ammonium phosphate based NPK fertilizers are clearly more amenable to placement at high rates. Except under abnormally dry conditions, dressings supplying up to 100 kg N/ha, the highest rate that would normally be encountered, can safely be placed in bands 5 cm directly below the seed; in practice, the N recommendation seldom exceeds 80 kg and on phosphate responsive soils accompanying P dressings of up to 40 kg/ha can be expected to be as effective as twice the amount broadcast. The results, therefore, provide a good illustration of the need for updating practical information on different aspects of fertilizer practice to cover changes in fertilizer composition. 603, 608, 5701, 5703

Time of Application of Nitrogen to Barley. Experiments on barley and oats carried out 25 years ago, including some collaborative work in the Scottish Colleges of Agriculture under the aegis of the then Field Trials Committee of the Scottish Agricultural Improvement Council, showed no appreciable or consistent difference in effectiveness between late and split applications of nitrogen compared with the normal seed-time dressings. Since then, however, there have been marked increases in the readily soluble nitrate content and rates of application of commercial fertilizers. It was considered desirable, therefore, to re-examine the question of time of application of nitrogen for spring cereals, with particular reference to possible leaching losses from seed-time dressings. A series of barley experiments was accordingly started in 1975 to compare the effects of 50 and 100 kg N/ha as Nitro-chalk applied at seed-time and about six weeks later, at the two to three leaf stage. As mentioned in last year's Report, experiments on normal agricultural land again showed no differences attributable to the time of application, even when the rainfall during the intervening period was above average. To complete the series, attention was, therefore, concentrated on light textured soils, where leaching losses are most likely to be encountered. Even under these conditions, however, there has been no indication of any clear differences in effectiveness between the seed-time and later dressings. The full results from the 1979 experiments are not yet available, but it seems safe to conclude that, as found 25 years ago with the nitrogen treatments then employed, current seed-time applications of nitrogen are not normally subject to any serious leaching losses under the conditions in north-east Scotland, and can be expected to be fully as effective as later top-dressings. 603, 608, 5701, 5703

Effects of Minimum Cultivation Methods on Barley. An experiment started in 1975 has been continued to compare normal ploughing, chisel ploughing and no ploughing in relation to broadcast and combine-drilled applications of superphosphate. The experiment is on a soil of the Tarves series, which is responsive to placement of phosphate, due to fairly high retention capacity reinforced by relatively high influence of strong binding by iron. Features of the individual years have been recorded in the last three Reports, and the mean results for three years were contributed to a pamphlet produced by the Scottish Agricultural Colleges and the Scottish Institute of Agricultural Engineering for Open Days on Direct Drilling in Scotland, held at the Bush Estate, Edinburgh, in June, 1979. Normal ploughing has consistently given the highest yields, the average yield of oven-dry grain being 0·5 t/ha greater than from chisel ploughing and no ploughing. The mean responses to 12·5 and 25 kg P/ha broadcast were 0·30, 0·31 and 0·13 t/ha grain, respectively, for normal ploughing, chisel ploughing and no ploughing. The corresponding values for phosphate combine-drilled with the seed were 0·39, 0·48 and 0·09 t. The level of P response was, therefore, smallest on the no ploughing plots, and contrary to what might be expected the greater penetration provided by combine-drilling did not produce any improvement in this respect. One factor regulating both the yield and phosphate comparisons, however, may be the fact that all the treatments have so far received the same rate of nitrogen. Work elsewhere has indicated that with less cultivation more nitrogen is required to attain the same yield, and it is intended in due course to introduce differential nitrogen treatments to clarify this aspect. 608, 5701, 5703

Nitrogen on Grass — White Clover Swards. An experiment on the nitrogen economy of swards of S23 ryegrass, alone or in combination with S100 or Blanca white clover, has been continued, in conjunction with parallel trials (ADAS/ARC Grass: White Clover Experiment GM23) being carried out at contrasting sites elsewhere in Britain. Six cuts were taken in 1978. Without fertilizer nitrogen, the dry matter yield from ryegrass alone was only 0·8 t/ha, compared with 5·5 t from the corresponding mixed sward of ryegrass plus S100, and 4 t from the ryegrass-Blanca clover mixture. With fertilizer nitrogen added, however, the yields from ryegrass alone increased rapidly, reaching 12·6 t/ha on the plots receiving 500 k N/ha. To extend the standard coverage in this experiment, additional treatments have been incorporated involving combined applications of boron, cobalt, copper, molybdenum and zinc, but these have not so far produced any increases in yield compared with the corresponding treatments with no trace element additions. 603, 608, 609, 5206, 5701, 5703

Crop Growth and Development

Detailed studies of a physiological nature under this head were initiated in 1969 as an essential complement to the more extensive field experimentation described above, which had hitherto been the prime requirement from both the research and advisory points of view. The main objective continues to be fuller understanding of the effects and interactions of fertilizers, environmental factors, soil conditions and husbandry practices. It was accepted at the outset that the programme would have to be developed over a considerable number of years before wider conclusions could safely be drawn. In several respects this stage has now been reached. Adequate bodies of detailed information, covering up to 10 seasons and a selection of contrasting soil series and field sites, have been obtained on the progressive accumulation of dry matter and nutrients in the barley, swede and potato crops and their constituent parts, and on associated local variations in soil and air temperatures, rainfall, humidity and wind speeds. As summarized in recent Reports, accounts of some features of the results have already been published, and two further papers are on the way, one dealing with swede sampling methods[2] and the other with changes in barley straw weight during grain filling[3]. Much remains to be evaluated, however, and until this has been done the experimental work will concentrate on a number of more specific questions which have already emerged. For example, the results obtained on the effects of date of sowing of swedes suggested that more fertilizer N was required for early compared with late sown crops. Three further experiments, not yet harvested, were therefore laid down in 1979 to check this finding. Similarly, the shape of the N response curve is being examined in more detail using six rates of applied N, to see whether as found for barley, it can be described by intersecting straight lines.

Further work has also been done on the effects of soil pH on the growth, nutrient uptake and yield of barley, with particular reference to implications concerning nitrogen supply and requirements, and to related studies, summarized later, on the chemistry of soil acidity. An experiment involving five rates of N and three pH levels has been continued on a soil of the Foudland series, with an initial pH of 5·0, measured in water suspension. Plots limed to target pH levels of 5·45 and 5·9 in the winter of 1977 — 78 were found a year later to have actual pH values of 5·65 and 6·25. The 1979 results fully confirm the pattern found in 1978 at this site. The unlimed plots gave the lowest yields, especially at low N rates. With inadequate N, the yield was also lower at pH 5·65 than at 6·25, but with adequate N there was no yield difference between these two treatments. In marked contrast to this, the yield at the pH 5·5 level in a parallel experiment on a soil of the Countesswells series was lower than at 6·2 irrespective of the amount of added N. In conjunction with the detailed studies in progress on the chemistry of soil acidity, further examination of soil samples from these experiments is projected to clarify the nature of this contrast. 607, 604

Together with an additional pH level of 4·5, obtained by acidifying with aluminium sulphate, samples from the limed and unlimed plots of the Foudland soil are also being used in a pot culture study on N-P-pH relationships, using an incomplete factorial design. The preliminary results indicate that, as would be expected, the response to P was much larger at low pH, but in contrast to the field results the response to N was severely restricted.
607, 604, 605, 606

Work has also been continued on the growth and development of swedes, including comparisons between the cultivar Doon Major, for many years the most popular cutlivar and the standard experimental test crop in the north of Scotland area, and the newer cultivar Ruta Øtofte, which has been found by the Scottish Colleges of Agriculture to produce about 16 per cent more dry matter. Two experiments carried out in 1978 in the present programme have confirmed this superiority, the difference in favour of Ruta Øtofte being about 20 per cent. The root growth of Ruta Øtofte was more rapid in the early part of the season and it produced 1·05 t/ha more dry matter by the end of August. It also maintained its leaf area better than

Doon Major, thereby allowing a small advantage in root growth rate to persist for the rest of the season to give a 20 per cent yield advantage of 1·55 t dry matter/ha. This advantage was due entirely to the higher percentage dry matter content of the Ruta Øtofte roots because there was no difference between the yields of fresh roots. Work on these cultivars has been continued in 1979, and a wider assessment of the potential productivity of swedes has been prepared for publication. This compares the yields of dry matter from swedes and 24 field experiments with corresponding barley yields from experiments at the same farms in the same seasons, and it is shown that swedes are capable of producing about 50 per cent more dry matter than barley. Some physiological factors influencing swede yields are also identified and it is hoped that this may help plant breeders to find suitable breeding material. 607

Chemical Composition of Crops

When more basic studies were started in this area about 15 years ago, the main objective was to assist rational understanding of the wide variations encountered in the total nutrient contents of crops as revealed by the standard analyses of samples from the field experiment programme. To this end, the implications of a number of plant characteristics, especially the cation exchange capacity (CEC) and so-called excess base (EB) content of roots and aerial tissues were examined for different plant species and agricultural crops and cultivars, in relation to yield, composition, stage of growth, fertilizer treatment and soil type. Various significant interrelationships were found, but none sufficiently reliable and widely applicable to be of much practical use. Attention was, therefore, transferred to the usefulness of plant analyses at early growth stages as criteria of the nutritional status of crops and as indices of yield and fertilizer requirements, especially nitrogen, which is not amenable to reliable prior evaluation by soil testing. During recent years, therefore, the work has become closely integrated with the programme on crop growth and development described above.

An account of work described in last year's Report on calcium and magnesium fractions in barley has been submitted for publication[4], and further attention has been given to the diagnostic value of analyses of the young plants. As summarized in the 1975-76 Annual Report, No. 46, the latter studies have hitherto been based on the composition of the whole plants. The possibility is being examined, therefore, that individual leaves may give earlier and better indications of the nutritional status, especially for nitrogen. To ensure full coverage, weekly samples of individual leaves and whole plants have been taken from plots representing different levels of fertilizer N in a reference experiment at Craigiebuckler, to enable the relationships to be examined between final grain yield and the total N, nitrate, reduced N, and EB contents of the samples. As an alternative to such sampling, some preliminary tests have also been made of the feasibility of making field measurements of nitrate using Merkoquant strips. These strips were developed for rapid estimation of nitrate in water, but they can also be used for estimating nitrate in plant sap using a simple press. For

example, they have been used in this way for vegetable crops by the National Vegetable Research Station. When young cereal leaves were tested, however, it was found that plant pigments tended to mask the blue colour produced. This can be largely avoided by placing a drop of sap on a corner of the strip and allowing the nitrate to diffuse to the unstained part, but the whole procedure then becomes somewhat less convenient. Since it contains little pigment, sap from the stem bases was, therefore, tried instead, but in this case the much higher nitrate content made it very difficult to distinguish adequately between the nitrogen treatments. The final assessment of the value of these tests will have to be made by comparison with the total N contents of the samples. Quite apart from any analytical difficulties, however, the usefulness of nitrate measurements may well be considerably restricted due to the well-known diurnal variation of nitrate levels in plants.
606

Parallel investigations have been continued on the composition of leaves of young swede plants. The response of swedes to nitrogen is much smaller than for barley, so that the yield curve very often flattens after one or two increments of added N, thereby restricting correlations between the final root yields and the composition of the young leaves. The accumulated data is accordingly being re-examined to see whether a minimum leaf N content can be specified, at a suitable stage of growth, which ensures that N fertilization is adequate for optimum yield. A limiting factor in this respect, however, may well be the fact that swedes, unlike cereals, do not reach an easily recognizable state of maturity, but are left in the ground to be harvested as required, often, depending on the season, with quite large increases in yield during the later stages. To clarify this and other features of the growth and development of the crop, a study has been started of the forms and amounts of soluble carbohydrates in the leaves at different stages of growth, to establish the pattern and rate of movement into the bulb. The material for this study is provided by a field experiment incorporating three N and two P levels, and concurrent information is being obtained on changes in the mineral composition of the leaves in relation to age and position.
606, 607

Trace Elements

The main objective of this programme continues to be fuller understanding of the trace element status of the main agricultural crops on different soil series, in relation to problems not only of crop production, but also of animal nutrition. From the outset in the middle 1930s, therefore, particular attention has always been given to influences of soil properties, parent material and drainage status, to the composition and stage of growth as well as the yields of crops and herbage, to occurrences of excesses as well as deficiencies, to the development of effective diagnostic methods for use in advisory soil testing, and to effects of liming and fertilizer treatments as well as trace element amendments. Another essential feature has been collaboration with animal nutrition workers, especially at the Rowett and Moredun Research Institutes, and with the Agricultural Advisers and Veterinary Investigations Officers of the North of Scotland College of

Agriculture. The research programme, therefore, has always been closely allied with the advisory soil testing work, described later, and indeed much of the experimental work has originated directly from advisory problems.

609

Since the essential soil and crop analyses involved necessitate specialist expertise and instrumental facilities, the trace element programme as a whole has always been carried out in collaboration with the Department of Spectrochemistry. The scale and content of the work accordingly increased commensurately over the years with the advances in Spectrochemical methods and facilities and in the field experiment and pot culture capabilities of the Department of Soil Fertility. The main expansions in both these respects started in the 1950s, and a recent joint paper summarizes many of the practical findings that have emerged during the past 20 years. This paper[5] was presented at a Symposium on Trace Elements in Soils, Plants and Animals, organized by the Agriculture Group of the Society of Chemical Industry. The results refer to herbage from temporary grassland cut three or four times per annum over periods of three years, to measure effects of cobalt, copper, molybdenum or zinc supplements, applied about three months before the first cut. Yield responses of herbage to trace elements on Scottish soils are usually negligible. The emphasis in most of this work, therefore, was on trace element content, which is important in relation to animal nutrition, including effects of stage of growth, botanical composition, and high nitrogen dressings. For example, although nitrogen tends to decrease the cobalt content of mixed herbage, the early finding is still valid that 2·2 kg/ha of cobalt sulphate (0·45 kg Co) is effective for at least two years in ensuring enough for ruminants. In the case of copper, the botanical composition of the herbage, as well as the copper status of the soil, is important, because clovers normally have a higher content than grasses. By decreasing the proportion of clovers, light to moderate dressings of nitrogen can, therefore, lower considerably the copper content in mixed herbage. On soils with an adequate copper status, however, including deficient soils treated with copper sulphate, high nitrogen generally produces counterbalancing increases in the copper content of the grasses. Even on deficient soils, however, a normal dressing of 22·4 kg/ha of copper sulphate (5·7 kg Cu) usually produces no increase in yield, and only small increases, usually less than 20 per cent, in the copper content of the mixed herbage, while on soils with adequate status there is no measurable effect. In contrast to this, such dressings give large increases in the yields of oats and barley on deficient soils, accompanied usually by some increase in copper content, and have marked residual effects lasting for up to 20 years. Nitrogen generally decreases the molybdenum content both in the grasses and the mixed herbage, even when a dressing has been applied. Uptake of molybdenum, unlike most other trace elements, can be markedly increased by liming, and caution is necessary in this respect. The molybdenum content of herbage, especially clovers, also varies during the season, and on plots treated with 1·1 kg/ha of sodium molybdate (0·44 kg Mo), for example, was much higher in samples collected in August and October. The zinc content of mixed herbage, on the other hand, is fairly stable, showing

little effect of applied nitrogen, little seasonal variation, and only a small increase following addition of 22·4 kg/ha of zinc sulphate (5·1 kg Zn).
609, 201, 202

Another joint paper[6] with the Department of Spectrochemistry, on Effects of Copper in Distillery Wastes on Soils and Plants, was presented at an International Conference on Management and Control of Heavy Metals in the Environment, in London. This deals with the cumulative effects from the disposal of pot ale, a liquid waste from the production of malt whisky, which normally contains 150 to 500 mg Cu per kg dry matter. Some of the disposal areas, mainly rough grazings, have been in use for more than 70 years and samples of the surface soil now contain up to 300 mg Cu/kg air-dry soil (<2 mm) extractable with 0·05M EDTA, compared with normal values of 1 to 5. As indicated in recent Reports, however, virtually all the applied copper has been retained in the upper 20 to 30 cm of soil, with the result that 50 to 80 per cent of the total soil Cu is extractable with EDTA, compared with about 10 to 20 per cent in normal soils. Although there is no evidence of penetration beyond this depth, the subsoil immediately below the enriched layer shows increased extractability, presumably due to downward leaching of soluble organic constituents of the pot ale. Field tests in 1978 on a site with about 300 mg EDTA extractable Cu/kg top soil showed that this exceptionally high level drastically impaired the germination of oats, less than 10 per cent of the seed producing plants, and severely reduced the growth of rape. Barley, ryegrass, clover, swedes and potatoes, however, grew satisfactorily and produced normal yields. The copper contents of plant samples at different stages of growth, including the oats and rape, ranged from 7 to 26 mg Cu/kg dry matter, with only clover, potato haulms and swede leaves containing more than 20 mg. Tests with the same range of crops in 1979 are giving practically identical results. On another site with similar EDTA extractable copper, which had been ploughed and reseeded in 1976, samples of mixed herbage, ryegrass and clover from a plot fenced off for the month of June, after intensive grazing, contained only 11 to 13 mg Cu/kg dry matter. 609, 201, 202

In other experiments, on normal agricultural land, measurements have been continued of the residual effects of copper treatments applied 20 years ago on the yield and copper content of crops and herbage. An experiment comparing the effectiveness of copper sulphate, copper oxychloride and a commercial slag has also been continued, and as mentioned earlier effects of trace element supplements are also being examined in the experiment in progress on effects of nitrogen on grass-clover swards. 609, 201, 202

Nitrogen

In keeping with the central importance of nitrogen supply as a prime regulator of crop production, measurements of the effects of fertilizer N on the yields and mineral composition of crops have always been important features of the field experiment programme. As indicated in the sections above, this continues to be the case, and appropriate supplementary monitoring of inorganic N levels in field plots has also been continued. In addition, soils from 10 field experiments measuring N responses of barley were cropped in pot cultures to obtain parallel measurements with oats, including samples at intermediate stages of growth, as a basis for further examination of the usefulness as indices of N status of a selection of soil N measurements found promising in earlier work, and as an aid to linking pot and field performance. 603, 606, 607, 608, 609

Phosphorus

The great majority of Scottish soils are naturally acid and deficient in phosphate, and have relatively high capacities for converting, or fixing, soluble fertilizer phosphate into less soluble, less available, forms. In contrast to this, a plentiful supply of phosphate is especially important for all the agricultural crops concerned. Of these, turnips, swedes and potatoes are all highly responsive, and adequate phosphate is also important for the grassland and cereals, not only for full yields but also, in the former case, to ensure good establishment of rotational swards and sufficient content in the herbage for animal nutrition, and in the case of barley and oats to promote earlier, more timely, maturity. From the outset, therefore, phosphate studies have been major features of the research programme. During the period of about 1950 to 1965, especially, extensive development of closely integrated field, pot culture and soil chemical studies produced important advances (a) in characterizing the influences of parent material and pedological drainage status on the phosphate relationships in different soil series, (b) in documenting the benefits from phosphate placement, (c) in clarifying influences of ploughing and cultivations on the concentration and positional availability of broadcast phosphate, (d) in evaluating the effectiveness of phosphate fertilizer residues, (e) in formulating average recommendations for different crops and soils, (f) in understanding the implications of different forms, times and frequencies of application, (g) in interpreting the significance and potentialities of different types of laboratory extraction methods for evaluating the phosphate status of soils, and finally, (h) in rationalizing the main features of all these aspects of soil-phosphate-crop relationships in terms of key crop characteristics and pivotal soil properties, especially pH, absolute and relative contents of reactive aluminium and iron, phosphate sorption capacity and degree of saturation, and the broader implications of the Quantity and Intensity aspects of phosphate supply. The current activities are concerned mainly with field and pot culture evaluation of the effectiveness of various commercial phosphate fertilizers incorporating rock phosphates and with continuing evaluation of experimental data and various subsidiary considerations relating to a major reappraisal, mentioned in last year's Report, of possible improvements in advisory soil testing procedures. 601, 608

The above studies involved mainly inorganic phosphate, but during the same period major advances were also made in identifying the nature, occurrence and significance of the various organic phosphorus compounds in soils, which in most Scottish soils account for about one-half, or more, of the total phosphorus. The detailed studies under this head, however, are now centred in the Department of Soil Organic Chemistry. 602, 317

Much still remains to be clarified concerning the mechanisms and kinetics of the supply of phosphate by soils to crops. The emphasis in recent years, therefore, has been on more basic physiochemical studies of the behaviour of inorganic phosphate in soils. An account of work on extraction of phosphate by anion-exchange resins, described in last year's Report, has been accepted for publication[7]. Progress has also been made in studying the phosphate status of different soils using adsorption-desorption curves, in which the Quantity (Q) of available P is related to its Intensity (I), measured by the concentration maintained in solution, and the slope defines the buffer capacity of the soil for P. Crop response to these parameters was examined by taking five cuts of ryegrass in pot cultures from samples representing four previously equilibrated incremental P levels for each of eight contrasting soils with differing Q/I curves. Two measurements of Q have been made, namely Pe, the amount exchanging isotopically over 24 hours, and Pr, the amount extracted with the bicarbonate form of an anion-exchange resin over 300 hours. These two values are not only closely correlated, but also numerically similar. Phosphate uptake by the grass at a given Q level from soils with contrasting Q/I curves varied as much as two-fold at every stage of growth, thus confirming the importance of P buffer capacity in regulating the supply of crops. Soil measurements made before and after cropping showed that the decrease in Q values was much less than the P uptake by the grass, and in some of the soils there was very little decrease in the I value due to cropping. The P uptake by the grass in this experiment could not, therefore, have been predicted directly from the Q/I curves, no doubt due to mobilization during cropping of P fractions not measured by these parameters as determined. This result has important implications in relation to release and utilization of P fertilizer residues, which in Scottish agricultural soils account for upwards of one-third of the total inorganic P, and to the problem of laboratory evaluation of soil phosphate status. 605

Sulphur

When work in this area was started during the 1960s, there was no reason to suspect any possibility of sulphur deficiency in agricultural land in north Scotland. On the contrary, it could safely be accepted that the large incidental additions of sulphate commonly made in fertilizers, especially superphosphate and ammonium sulphate, ensured that crop requirements were adequately met. Until recent years, therefore, the experimental emphasis was largely on the nature, distribution and properties of the compounds comprising the organic S fraction, which in acid soils normally accounts for 98 per cent or more of the total S. These studies were complementary to the detailed work on soil organic phosphorus mentioned above, and as mentioned in recent Reports the main findings have been published. In collaboration with the Department of Soil Organic Chemistry, attention continues to be given to organic soil S, especially identification and estimation of sulphur-containing amino acids in different soil types in relation to the C-bonded S fraction. The recent emphasis, however, has been mainly on the inorganic sulphate status of agricultural soils, because a survey has shown that some of these, especially sandy soils of the Boyndie series, have phosphate-extractable sulphate contents below 12 ppm S, regarded in the literature as a level below which deficiency is liable to affect plant growth. These soils do, in fact, give marked responses to added S in pot cultures, and an account of the results has been published[8]. 601, 602

Pot culture work has accordingly been continued to study further the significance of low soil S status in terms of the growth, chemical composition and protein quality of ryegrass, cocksfoot, timothy and white clover. In all cases, on all four of the sandy soils used, yield responses to added sulphate were obtained, and the plants are being analyzed to determine total S, total N, total SO_4, and the total N/S ratio. Using oats as indicator crop, a pot culture evaluation has also been made of the S status of 10 contrasting soils, to enable the usefulness to be gauged of soil S values estimated by seven different methods, including L-values measured with radioactive ^{35}S. The correlations with yield and yield response ranged from 0·38 to 0·70, and in several instances, including the L-value, were not statistically significant. The correlations with S uptake, however, were all in the range 0·81 to 0·91 and all highly significant. As in the analogous case of phosphate, though probably for somewhat different reasons, the L-value correlated much better with S uptake than with the yield data, but in all respects the best relationships were given by the total sulphate extracted with potassium phosphate or sodium bicarbonate. 601, 602, 613, 5613

Marked pot responses to added S are being obtained even though the cultures are exposed to gaseous atmospheric S and to S in rainfall. Attention is, therefore, being given to the implications of these sources, particularly since their potential practical importance has been enhanced by the virtual elimination of incidental additions of sulphate to agricultural land, due to the increased purity and concentration of commercial fertilizers. A review of the relevant literature has been published[9], and to examine the effects of S from rainfall, oats have been grown in pot cultures in two contrasting environments, both open to gaseous atmospheric S, but one protected from rainfall. Clear differences in growth and responses to added sulphate were found, attributable to the rainfall input of about 10 kg S/ha during the season, and an account of the results has been published[10]. Gaseous atmospheric S at the pot culture site in the Institute grounds has also been measured, and the initial indications are that the concentration is about 40 $\mu g\ SO_2/m^{-3}$. The more intensive growth conditions and nutrient extraction in pot cultures are, of course, conducive to larger responses than in the field. Even so, this relatively high SO_2 concentration makes the pot responses more difficult to understand, and further work is necessary to clarify the utilization of atmospheric S. 601

From the practical point of view, of course, the crucial question is whether responses to added sulphate, in terms of yield and/or crop composition, can be obtained under normal field conditions, especially on soils with relatively low phosphate-extractable S which have responded in pot cultures. Experiments were, therefore, laid down at three such centres, one testing oats, one testing mixed herbage, and the third testing barley and ryegrass. Samples, including some at early stages of growth, have been taken to examine the effects of added potassium sulphate on crop composition, but so far only the yields are available. In agreement with earlier field tests on barley, there was no sign of any yield response in the two cereal experiments. At applied nitrogen levels of 100 to 160 kg N/ha per cut, however, addition of potassium sulphate increased the yield of dry matter by about 8 per cent in the case of ryegrass and 5 per cent in the case of the mixed herbage. Only the former increase borders on statistical significance, and the chemical composition of the crops remains to be examined. Even so, these findings constitute the first signs of possible field deficiencies affecting yield, and further trials are clearly necessary. 608, 601

Soil Acidity and Cation Exchange

It has long been appreciated that adequate liming is essential for efficient crop production on most Scottish soils. By about the middle 1950s, field experiments and supporting soil analyses had enabled generally suitable lime levels to be defined, and provided the basis for establishing an effective soil testing procedure for advisory estimation of lime requirements. With occasional adjustments and refinements, in the light of increasing knowledge and better understanding of soil-crop relationships and the characteristics of different soil series, this procedure has continued to provide effective practical lime recommendations. It has also played an important part in the major improvement which has taken place in the lime status of agricultural land, as shown by the fact that about 30 per cent of the advisory soil samples are currently rated as having an adequate lime status, compared with only about 5 per cent 30 years ago. Much still remains to be clarified, however, concerning the detailed nature and implications of soil acidity in different soil series, and it became evident in the later 1960s that more basic studies in this area were essential before a new generation of liming experiments could be properly planned to reappraise the effect of soil acidity on crop growth, to reassess suitable lime levels, including long-term implications, and to examine possibilities of further improvement of advisory soil testing. 604, 608, 609, 610

Detailed studies on cation exchange processes and the nature of soil acidity in different soil series, especially aluminium-organic matter—pH relationships, were, therefore, initiated and are being continued. Progress has been made in studying variations in ion concentrations in solution during the growing season in a granitic soil under barley and permanent grass in the field, using the composition of saturation water extracts of soil samples taken at monthly intervals. The total salt concentrations varied only twofold under grass, but more than fivefold under barley. No doubt the latter wider variation was due partly to different fertilizer treatment, but there was also a considerable rise in sulphate concentration in mid season, the reason for which is not at present clear. Results from a detailed liming experiment in pots on acid soils with a wide range of organic matter contents are also being examined. The purpose is to quantify the role of organic matter both in the buffering reactions that govern soil pH and in relation to the solubility and ionic speciation of aluminium as a function of pH. The interactions of aluminium with water-soluble soil organic matter fractions are also being investigated in the laboratory, using ultrafiltration membranes to separate free Al ions from the reaction products and analytic mathematical techniques to calculate stability constants. These latter studies form the main theme of a PhD programme, mentioned earlier, being carried out by Mr S. D. Young. 604

Five encyclopaedia articles mentioned in recent Reports[11-15] and two other papers[16, 17] have now been published. An account of a lecture on the uptake of some major mineral elements by plants delivered at the Rank Prize Funds International Symposium, Kenilworth, April, 1979, has also been submitted for publication[18].

Potassium and Magnesium

In keeping with regular use of farmyard manure and the presence of considerable mineral reserves, the potassium status of agricultural soils in north Scotland has always been very favourable compared with phosphate and lime. For example, the proportion of advisory soil samples rated as low as only about 15 per cent 40 years ago and is now down to about 2 per cent, compared with the corresponding figures of about 40 and 20 per cent for phosphate. Until about five years ago, therefore, work on potassium was largely confined to field measurements of crop responses on different soil series, to improve the basis for formulating practical fertilizer recommendations and for calibrating measurements of readily soluble soil potassium for advisory purposes. The importance of potassium supply, however, has been enhanced by greater removals in larger crops and by its key role in promoting efficient utilization of nitrogen in intensive grass production. Similiarly, although no convincing instance of yield restriction attributable to magnesium deficiency has so far been encountered in north Scotland, the importance of the magnesium status of soils and crops has increased in relation to animal nutrition. 608, 610

Detailed studies were, therefore, started in 1975 on the potassium and magnesium supplying power of selected contrasting soil series, with particular reference to Quantity-Intensity relationships, to release and evaluation of conventionally non-exchangeable reserves, to potassium-magnesium interactions, and to implications of differences in clay mineralogy. Two papers[19, 20] describing work summarized in last year's Report on release of soil potassium and its uptake by ryegrass have appeared, and an account[21] has been accepted for publication of a study on the desorption of soil cations by electro-ultrafiltration (EUF). This technique involves the extraction of nutrient ions from aqueous soil suspensions under the influence of an applied electric potential, with continuous removal of the extracted nutrients at nearly constant pH. Compared with conventional fractionations using successive extractions, the method has the advantage that by using three different voltages (50, 200 and 400) for different times several cation fractions are obtained in a single run lasting 35 minutes. The pattern of release under these conditions gives information on cation concentrations in the soil solution and the effects of fertilizers, as well as on the exchangeable cation fractions. Except for the sandy loam soils used, potassium desorbed by EUF in 10 minutes was very highly correlated ($r=0\cdot97$) with the equilibrium activity ratio of soil K measured in 10^{-2}M $CaCl_2$ solution, while over all the soils concerned, potassium desorbed in 35 minutes was less than the exchangeable amount but closely correlated with it ($r=0\cdot98$). For the prediction of uptake by ryegrass from 10 soils during intensive glasshouse cropping, EUF values for both potassium and sodium compared favourably with conventional parameters. The uptake by ryegrass of intially non-exchangeable potassium in equilibrium with the exchangeable pool was predictable from the EUF fractionation, but uptake of potassium released from the interlayers of clay minerals was not. EUF extraction is less satisfactory for magnesium than for potassium, sodium and calcium, owing to precipitation of magnesium hydroxide on the cathode filter. Magnesium availability, however, including the pattern of release from different soils, has also been studied by continuous glasshouse cropping with ryegrass and the results are being processed for publication. 611

Electrochemical Techniques

Studies in this field were first started in 1976. The main developments envisaged are (a) determination of plant nutrients and differentiation of ionic species in soil and plant extracts, (b) direct measurement of nutrients in moist soil and *in situ* monitoring of the pattern of nutrient supply in the field, (c) application of physico-chemical concepts and principles, especially Quantity-Intensity relationships, in studies on the availability and mobility of trace elements in soils, especially heavy metals, and (d) miniaturization of equipment to simulate nutrient uptake by roots and to examine soil heterogenity and the root-soil interface. The emphasis so far has of necessity been on the development and improvement of analytical methods employing ion selective electrodes, differential pulse polarography and ion stripping voltammetry, but progress is now being made also in the application of these techniques in studies on selenium and molybdenum relationships in soils. Work in both areas has been greatly facilitated by the commissioning during the year of an air-conditioned electrochemical laboratory.

The conventional dropping mercury electrode previously used for electrochemical determinations has been replaced by a static mercury drop electrode, which permits more rapid analyses, provides lower detection limits, and is better suited to computer control. For the determination of various trace metals in small ($0\cdot3$ to $1\cdot5$ cm^3) volumes of solution, stationary electrodes, such as glassy carbon and mercury film electrodes, are being investigated, in collaboration with Mr Pu, Department of Chemistry, Hofei University, China, who, as mentioned earlier, is currently visiting the department. An account[22] has been published of the improved signal acquisition and data processing system summarized in the previous year's Report. 614

Molybdenum. The above system has lowered by a factor of four the detection limit of the method which has been developed for determining molybdenum in soil extracts, using differential pulse polarography in $0\cdot6$M nitric acid. An account of this method has been accepted for publication[23], including an equation which has been developed to characterize the peak current obtained for the differential pulse polarographic determination of catalytic waves, taking account of electrode area, electrolyte and analyte concentration, the mechanism and rate constant of the reaction, and the height and measurement time of the pulse. This equation has been used to establish the reaction pathway and kinetics of the electrochemical reduction of Mo^{VI} in nitrate media. The key species appears to be electrochemically generated Mo^{IV}, which is rapidly oxidized by nitrate, thus replenishing the Mo^{V} species for further reduction. Using this method, work has been started on the solubility and sorption relationships of molybdenum in different soil series. 614

Selenium. Following the appointment of Dr S. Cooke to succeed Dr G. P. Bound, work has been resumed on the cathodic stripping technique for determining selenium, with particular emphasis on improving the detection limit. The problem of peak splitting below 10 ppb can now be largely controlled by selecting a suitable mercury drop size and background electrolyte concentration. Interference from accompanying metal ions in soil extracts is greatly decreased by preconcentration of the selenium on an anion-exchange resin, but serious interference due to a chloride stripping peak remains and cannot be eliminated, because selenium deposition must take place in a chloride medium. The method is being applied to study the extraction of selenium from treated and untreated soils from field plots, using different types of extraction methods, including anion-exchange resin. In keeping with its low uptake by crops, one feature which has already emerged is that the binding of selenite by the soil colloids is so strong that the amount extracted by resin in aqueous suspensions is very low, being $<0 \cdot 2$ ppb even from the treated soils. 614

Soil Physics

This programme is also a very recent venture, initiated effectively about three years ago and still in an early stage of development. Following the major advances made during the period of about 1950 to 1970 in characterizing and improving the lime and nutrient status of agricultural soils through research on chemical aspects of soil-nutrient-crop relationships combined with advisory soil testing, the time was considered ripe to pay more attention to possible soil physical constraints on crop production. The main objectives, therefore, are to investigate influences of soil physical factors on the growth and yields of crops and to characterize the physical properties of different soil series. The first requirement was to appraise current research activities, including visits to appropriate centres in Britain and Western Europe, in order to assess the relevance of different areas of work to Scottish conditions and to establish appropriate laboratory and instrumental facilities. Good progress has been made in all these directions. During the year a new laboratory with temperature and humidity control has been provided by conversion of space previously used for soil storage, which will greatly extend the range of studies than can be undertaken. As summarized below, progress has also been made in an energy balance study and in characterizing soil series. 612

Soil Energy Balance. Soil temperature in spring is of prime importance for crop growth, especially in northern regions. A physically-based study of soil temperature in terms of its meteorological driving mechanisms is, therefore, being developed. To this end a theoretical analysis of the surface energy balance has been made and, with the cooperation of the North of Scotland College of Agriculture, a field site has been established and instrumented to provide experimental data for testing the analytical model. This model is designed to predict from meteorological variables and soil parameters the average daily variation of surface temperature over periods of about one to three weeks. Since this type of approach should ultimately be of greater practical usefulness, the emphasis is on characterising average variations of soil temperature for an area at a given time of the year, rather than on detailed microvariations over much briefer periods.

Promising agreement has been obtained between the experimental data and results predicted from the analytical model. The first period studied covered 20 days during September, 1978, when the bare soil surface remained continously wet, and the diurnal temperature wave spanned the range 7·9 to 16·3°C. The predicted wave agreed well with the observed one, the mean discrepancy over 24 hours being less than 0·5°C. This particular version of the model, however, required the assumption of a constant windspeed, whereas a strong diurnal pattern is usually observed, typically with higher daytime values. An improved version of the model has, therefore. been devised, capable of accepting varying windspeed, which should improve the accuracy of the predicted temperature wave. Further extensions of the theory are being made, including treatment of soil thermal " memory," so that the modelling of soil temperature may be narrowed to variation over a single day. Technical developments include acquisition of field data using a magnetic cartridge logger and successful throughput to the Institute computer using the external-read interface of the logger, thereby facilitating more extensive testing and development of the energy balance models. At the field site, access tubes have also been installed to enable the soil moisture profile to be monitored with the neutron probe. Similarly, a psychrometer unit has been installed for automatic logging of air temperature and vapour pressure, and a sensitive anemometer is soon to be mounted, thus completing the range of instruments for *in situ* logging of all the essential meteorological variables, except for cloud cover, which is the least critical and for which visual estimates will continue to be required from the nearby Dyce Meteorological Station. 612

Characterization of Soil Series. Measurements of Bulk Density and Moisture Release Characteristic have been continued on a routine basis, including detailed coverage of the Strichen and Anniegathel series of the Strichen Association and the Blackhouse series of the Peterhead Association. With the assistance of the Department of Statistics, progress has also been made in a major evaluation of earlier data covering 12 soil series and over 100 profiles. 612

Radioisotope Unit

The main functions of this unit, which has been centred in the Department of Soil Fertility since 1974, are to establish and develop instrumentation, facilities and techniques for applying radioisotopes in soil and plant studies,

and to provide collaboration, advice and services in these respects throughout the Institute. A Packard Gamma Spectrometer with automatic sample change was obtained during the year and is proving very useful, especially for nutrient uptake experiments employing double labelling. Similarly, sample oxidising by combustion and collection of CO_2 in a scintillator for counting is proving efficient for ^{14}C work on soil organic matter, and is faster than the methods previously used. One account of collaborative work with the Department of Soil Organic Chemistry in the latter field has been published[23] and another submitted[25]. A joint paper[26] on plant uptake of ^{59}Fe has also appeared. Collaboration has also been continued with the Department of Plant Physiology, including a number of studies on plant uptake of ^{63}Ni. In the Soil Fertility programme, ^{35}S and ^{32}P continued to be used in studies on sulphur and phosphate relationships in soils.
613, 5613, 305, 309, 401, 601, 605

Advisory Work

As already stressed in the introduction, the soil fertility programme has from the foundation of the Institute been closely allied with advisory soil testing in collaboration with the North of Scotland College of Agriculture and with related consultative responsibilities, which together continue to provide the principal reciprocal link between research and practice. During the year nearly 7500 soil samples were submitted by the Advisory Officers of the College, of which all but 124 from horticultural and recreational areas were from agricultural land. This total is 1000 more than in 1977-78 and confirms a gratifying upward trend during the last three years. Acidity and lime requirement and phosphate, potassium and organic matter status were assessed for all the samples, magnesium for 926, and, in collaboration with the Department of Spectrochemistry, trace elements, mainly cobalt and copper, were determined in 627 cases. Liming value was estimated for nine materials, mainly shell sands, and 30 crop samples were analyzed in relation to abnormal problems of crop growth or animal health. In one field where heavy dressings of farmyard manure and slaughterhouse waste had been applied, abnormally high levels of nitrate were found, equivalent to 160 and 14,500 mg N per kg of soil and swede leaf dry matter, respectively. Again in collaboration with the Department of Spectrochemistry, the contents of potentially toxic elements were determined in 22 samples of sewage sludge from the Grampian Region. 610, 5205, 5206

Most of the requests for trace element determinations on soil samples relate to doubts or problems concerning animal health or performance. From both field experiment evidence and advisory experience, it appears that while most soils have adequate copper contents to produce full yields, practically all the crops, unless contaminated with soil, contain only 3 to 8 mg Cu per kg dry matter, which is less than the 10 mg quoted in the Agricultural Research Council recommendations for cattle. 609, 610, 5206

In collaboration with the Department of Peat and Forest Soils, lime status and major nutrients were also assessed for 141 soil samples from forest nurseries, and in four cases the copper status was also determined.
608, 117, 5206

References:

1. The piezoelectric sorption detector as a monitor of atmospheric pollutants. By S. Cooke, T. S. West and P. Watts. Submitted to *Proc. Analyt. Div. Chem. Soc.*
2. A comparison of two sampling methods for the estimation of dry matter and mineral content of swede roots. By P. W. Dyson. Submitted to *J. Sci. Fd Agric.*
3. Some factors affecting changes in straw dry weight during the grain filling period in barley and the influence of those changes on grain yield. By P. W. Dyson. Submitted to *Ann. Appl. Biol.*
4. Effect of soil pH and N fertilization on uptake and fractions of Ca and Mg in two barley cultivars. By W. M. Crooke. Submitted to *Commun. Soil Sci. Plant Anal.*
5. Effect of NPK fertilizers on trace element uptake by herbage. By J. W. S. Reith, J. C. Burridge and M. L. Berrow, *J. Sci. Fd Agric.*, **30**, 743, 1979.
6. Effects of copper in distillery wastes on soils and plants. By J. W. S. Reith, M. L. Berrow and J. C. Burridge, in *Proc. Int. Conf. Management and Control of Heavy Metals in the Environment*, 537-540. CEP Consultants Ltd., 26 Albany Street, Edinburgh, EH1 3QH.
7. Desorption of phosphate from soils using anion exchange resins. By B. W. Bache and C. Ireland. To appear in *J. Soil Sci.*
8. The sulphate status of soils from north Scotland. By N. M. Scott and J. Munro, *J. Sci. Fd Agric.*, **30**, 15-20, 1979.
9. Sulphur emissions in relations to sulphur in soils and crops. By B. W. Bache and N. M. Scott, in *Sulphur Emissions and the Environment*, 243-254. London: The Society of Chemical Industry, 1979.
10. Effect of sulphur in rain on the growth and sulphur responses of oats in pot cultures. By N. M. Scott, *J. Agric. Sci. Camb.*, **93**, 765-767, 1979.
11. Activity Ratio. By B. W. Bache, in *The Encyclopedia of Soil Science, Part 1*, 4-8. Edited by R. W. Fairbridge and C. W. Finkl. Stroudsburg, Pa.: Dowden, Hutchinson and Ross Inc., 1979.
12. Base Saturation. By B. W. Bache, in *The Encyclopedia of Soil Science, Part 1*, 38-42. Edited by R. W. Fairbridge and C. W. Finkl. Stroudsburg, Pa: Dowden, Hutchinson and Ross Inc., 1979.
13. Chemical Composition. By B. W. Bache, in *The Encyclopaedia of Soil Science, Part 1*, 67-70. Edited by R. W. Fairbridge and C. W. Finkl. Stroudsburg, Pa.: Dowden, Hutchinson and Ross Inc., 1979.
14. Soil Reaction. By B. W. Bache, in *The Encyclopedia of Soil Science, Part 1*, 487-492. Edited by R. W. Fairbridge and C. W. Finkl. Stroudsburg, Pa.: Dowden, Hutchinson and Ross Inc., 1979.
15. Soil Solution. By B. W. Bache, in *The Encyclopedia of Soil Science, Part 1*, 497-498. Edited by R. W. Fairbridge and C. W. Finkl. Stroudsburg, Pa.: Dowden, Hutchinson and Ross Inc., 1979.
16. The acidification of soils. By B. W. Bache, in *Effects of Acid Precipitation on Terrestrial Ecosystems*, 183-202. Plenum, New York, 1980. Edited by T. C. Hutchinson and M. Havas.
17. The sensitivity of soils to acidification. By B. W. Bache, in *Effects of Acid Precipitation on Terrestrial Ecosystems*, 569-572. Plenum, New York, 1980. Edited by T. C. Hutchinson and M. Havas.
18. Uptake of some major mineral elements by plants. By T. S. West and B. W. Bache. To be published in *Proc. Int. Symp. on Food Chains and Human Nutrition, Kenilworth, 1979.*
19. Availability of potassium to ryegrass from Scottish soils. I. Effects of intensive cropping on potassium parameters. By A. H. Sinclair, *J. Soil Sci.*, **30**, 757-773, 1979.
20. Availability of potassium to ryegrass from Scottish soils. II. Uptake of initially non-exchangeable potassium. By A. H. Sinclair, *J. Soil Sci.*, **30**, 775-783, 1979.
21. Desorption of cations from Scottish soils by electro-ultrafiltration. By A. H. Sinclair. Submitted to *J. Sci. Fd Agric.*
22. A microcomputer-based data acquisition and processing system for electrochemical analysis. By T. E. Edmonds, *Anal. Chim, Acta*, **108**, 155-160, 1979.
23. The differential pulse polarographic determination of molybdenum in nitrate media. By T. E. Edmonds. To appear in *Anal. Chim. Acta.*
24. Transformation of carbohydrate constituents of grass during decomposition in soil. By M. V. Cheshire, C. M. Mundie and H. Shepherd, *J. Sci. Fd Agric.*, **30**, 330, 1979.
25. Comparison of the contribution to soil organic matter fractions, particularly carbohydrates, made by plant residues and microbial products. By S. Murayama, M. V. Cheshire, C. M. Mundie, G. P. Sparling and H. Shepherd. To appear in *J. Sci. Fd Agric.*
26. A comparative study of the effects of natural and synthetic ligands on iron uptake by plants. By D. J. Linehan and H. Shepherd, *Pl. Soil*, **52**, 281-289, 1979.

8. STATISTICS

R. H. E. Inkson

The department provides a consultative and advisory service for research projects at the planning stage. Close collaboration with other departments is involved and has resulted in the development of considerable experience in the use of specialized techniques. After the planning stages, the service also includes the consequent facilities for data processing, statistical analysis, model-building and computer programming and operation.

Mr D. A. P. McKay, who had spent almost three years in the department as an ARC post graduate research student, joined the staff towards the end of the year and will continue to work on establishing appropriate systems for the storage, retrieval, analysis and presentation of soil information.

Members of staff have attended meetings and conferences of the Royal Statistical Society and of the IUFRO Mensuration, Growth and Yield (Subject Group S4·01). The department has also been represented at computer and microprocessor exhibitions and meetings, and visits have been made to computer installations to assess the suitability of different models.

Computing

The department provides computing facilities for the Institute and has responsibilities for operating and managing the system, and for providing the necessary programming support and data preparation equipment. The Commodore PET desk-top computer has had its memory expanded to 32 kilobytes and its facilities improved by the addition of a Teletype model 43KP printer and a second magnetic tape cassette unit.

A reappraisal of the Institute's computer requirements resulted in the placing of an order for a Data General Eclipse C/150 computer. This machine has 512K bytes of core memory and a 50M byte disk drive. It also has multiple access for video display terminals with keyboards, magnetic tape and diskette subsystems, and interfaces for other devices and laboratory equipment. Preparations are already in hand for the major task of transferring programs and data files to the new system. Further progress will be made with the Institute's main soil information system when the new computer is installed. 703

Peat and Forest Soils. Changes in laboratory methods have made it necessary to amend the program which processes data from auto-analysis to provide the concentration of elements in over-dried peat or tree parts and the uptake of elements in mg/litre in rainfall samples. Further changes were made to accept the input of peak height data from charts *via* the direct link between the Ferranti Cetec digitiser and the IBM 1130 computer. The processing of such data continues on a regular basis as does the plotting of profiles from whole-tree sampling, and the production of corrected percentages of oxides from nominal percentages obtained in X-ray silicate analysis. Stereoplotter digitised data is transmitted directly to the computer, stored, processed and subsequently contour maps are plotted. Assistance has also been given in the preliminary processing of Landsat data and in setting up a database system. Vegetational data from 156 sites on Lewis and Harris have added three files to those already stored.

104, 107, 111, 112, 114, 115, 116, 117, 703, 5703

Spectrochemistry. Advice and assistance have been given in processing data and plotting results from infrared, Mössbauer and electron paramagnetic resonance (EPR) studies. Further collaboration has been given in establishing a computer-based storage and retrieval system to assist in relating trace element data to other soil properties. 201, 203, 703, 5703

Soil Organic Chemistry. A program for the identification of amino acids and the calculation of peak areas and percentage composition of samples has now been tested for different sampling frequencies. A program was written for the Commadore PET to fit a double exponential decay curve of the form $Y = Ae^{-k_1 t} + (100-A)e^{-k_2 t}$. 303, 305, 703, 5703

Soil Fertility. A further subroutine for obtaining components of quality x quantity interactions has been made available for calls from a mainline analysis of variance program. A program has been developed for reading, storing and processing data from magnetic tape cartridges.

608, 612, 701, 703

Soil Survey. Regular use is made of the program which processes plant sociological data to produce the best groupings of species and sequences of stands. Two new sets of coding have been devised for the transcription of profile information from general survey records and from the hill land survey. A database system is being developed for the soil and site information on soil complexes. 801, 802, 703, 5703

Advisory and Collaborative Work

Peat and Forest Soils. The series of NPK experiments on Sitka spruce, of central composite design with additional treatments, continues to provide large quantities of data for processing and statistical analysis. In addition to the annual diameter measurements and analysis of foliage samples, two experiments had whole tree samples taken in spring 1979. Processing and statistical analysis are now carried out on needle area data which is provided by the image analyser in the department of Microbiology. Needle area profiles have been plotted in the same way as needle weight and number profiles. An account[1] of work on the cycling of nutrients in pine has now appeared. Further work[2] from experiments on the mineralization of nitrogen in peat has been accepted for publication and work[3] on the derivation of nutrient accumulation in Corsican pine at different growth rates has been submitted for publication. Regression analysis has been used in relating properties of rainwater collected in the open, as throughfall and as stemflow. A joint account of this work[4] has now been published. Analysis of variance and regression analyses have been carried out on data from experiments on reseeded and natural vegetation and from glasshouse experiments.

111, 115, 116, 117, 701, 703, 5701, 5703

Mineral Soils. Correlation and regression analyses were used to investigate the physical and, using a range of different extractants, chemical properties of soil samples from several horizons in a number of soil profiles.
103, 105, 5701, 5703

Spectrochemistry. Collaboration has been given in the use of criteria for tests of hypotheses in multivariate analysis, particularly in relation to the hypothesis that populations have the same dispersions, but may differ in their means, and the hypothesis that the populations have the same means given that they have the same dispersion. Correlation and regression analyses have been used in relating the soil contents of an element, extracted by different methods, to the content in a number of plants.
201, 701, 5701, 5703

Soil Organic Chemistry. An augmented 5 x 5 Latin square has been used for an experiment to investigate the effects of different crops on the equilibrium levels of a number of organic components in the soil and on soil enzyme activities. This experiment is continuing with a further set of crops planned for 1980. 311, 701

Individual and combined analyses of variance have been carried out on data from factorial experiments testing the effects on the growth of wheat plants of ABA, BA, GA, light and deseeding. 309, 5701, 5703

Work[5] on the decomposition of straw in soil using single and double exponential decay curves has been accepted for publication.
305, 703, 5701, 5703

Plant Physiology. The effects of iron, selenium, glucose, galactose and glucosamine factors have been tested in a number of experiments on the chemical composition and on the growth rate of Lemna. A joint account[6] of some of the work has been published. Joint accounts of work on the distribution of catalase and peroxidase[7] and of nutrients[8] in potatoes have now been published. The occurrence of blossom-end rot in tomatoes has been investigated in a number of experiments and the angular transformation of the percentage occurrence used. A joint account[9] of some of the experiments has been published. Other published collaborative work includes a series of experiments on plant leaf composition[10] and a series on cabbage and cauliflower[11] with nitrogen, calcium and molybdenum factors.

Microbiology. Multiple regression methods have been used in relating the numbers of anaerobic bacteria to various properties of peat at regular depth intervals in a deep basin peat. Relationships have been derived for different times of year. 503, 5701, 5703

Soil Fertility. The field experiment programme includes 45 new or continuing experiments each of which provides several sets of data for processing and statistical analysis. The highest number of variables analysed from a single field experiment was 189. The designs ranged in complexity from randomized blocks to central composite arrangements.
601, 603, 606, 607, 608, 609, 701, 5701

Further regression equations have been tested in the examination of field experiment results with a view to classifying the phosphate status of different soil types according to their responsiveness. 601, 5701, 5703

The detailed study of the pattern of growth and development of barley, oats and swedes continues with experiments of randomized block, factorial and split-plot designs. Various polynomial regression relationships have been tested in this work. The use of cores and segments of swedes, as a basis for determining the chemical composition and the percentage of dry matter, has been examined and the two methods compared in respect of variability as well as mean values. 607, 5701, 5703

Tests of differences between soil series and soil texture have been made for porosity measurements and regression relationships between porosity and water tension tested. 612, 5701, 5703

A data punching service has been provided for work on solar radiation, soil temperature and meteorological factors. Logarthmic and hyperbolic regression equations have been tested in relating resistance to temperature in thermistor calibration. 612, 5703

Correlation and regression analysis, and analysis of variance have been used in relating crop yield to excess base and nitrate values, in factorial pot experiments with sulphur treatments on cereals, in potassium pot experiments and in experiments measuring rates of K release from soils using electro-ultrafiltration. 601, 606, 607, 611, 5701, 5703

References:

1. Nutrient cycles in pine and their adaptation to poor soils. By H. G. Miller, J. M. Cooper, J. D. Miller and O. J. L. Pauline. *Can. J. For. Res.*, **9**, 19-26, 1979.
2. Some effects of afforestation with lodgepole pine on rates of nitrogen mineraliza-in peat. By B. L. Williams, J. M. Cooper and D. G. Pyatt (Forestry Commission). To appear in *Forestry*.
3. Biomass and nutrient accumulation at different growth rates in thinned plantations of Corsican pine. By H. G. Miller and J. M. Cooper. Submitted to *Forestry*.
4. Changes in sulphur content and acidity of rainwater on passing through the canopy of Sitka spruce forests. By H. G. Miller, J. D. Miller and J. M. Cooper, in *Proc. Int. Symp. Sulphur Emissions and the Environment*, 225-227. London, May 1979. The Society of Chemical Industries, Water and Environment Group, 1979.
5. The decomposition of straw in soil. By M. V. Cheshire, G. P. Sparling and R. H. E. Inkson. To appear in "*Straw decay and its effect on utilization and disposal.*" Edited by E. Grossbard. John Wiley and Sons Ltd.
6. The effect of galactose on the growth of *Lemna*. By P. C. DeKock, M. V. Cheshire, C. M. Mundie and R. H. E. Inkson, *New Phytol.*, **82**, 679-685, 1979.
7. A study of peroxidase and catalase distribution in the potato tuber. By P. C. De-Kock, A. Hall and R. H. E. Inkson, *Ann. Bot.*, **43**, 295-298, 1979.
8. Nutrient distribution in the potato tuber in relation to soil pH. By P. C. De-Kock, A. Hall and R. H. E. Inkson, *Ann. Bot.*, **43**, 299-304, 1979.
9. Blossom-end rot in tomatoes. By P. C. DeKock, A. Hall, R. H. E. Inkson and R. A. Robertson, *J. Sci. Fd Agric.*, **30**, 508-514, 1979.
10. Active iron in plant leaves. By P. C. DeKock, A. Hall and R. H. E. Inkson, *Ann. Bot.*, **43**, 737-740, 1979.
11. Nitrate reduction in plant leaves in relation to calcium. By P. C. DeKock, A. Hall, A. Naylor and R. H. E. Inkson, *Proc. 6th Long Ashton Symp. Nitrogen Assimilation of Plants*, **1**, 43-151, 1979.

9. SOIL SURVEY

R. Grant

Soil Survey activities in the past year have concentrated on the 1:250 000 mapping programme. During the winter months, aerial photography cover was acquired and some preliminary interpretation carried out, arrangements for access made and standardised terminology and recording cards for profile description produced. A standard method of recording mapping units was also devised. To assist soil surveyors in the recording of vegetation, a key to the common plant communities was prepared and distributed, while the cartographic section designed the necessary topographic base maps and began work on their compilation. It was also decided that with the 1:250 000 survey in progress the time would be opportune to compile a Soil Inventory for Scotland by describing and sampling the profiles at the 10 km National Grid intersects, with additional descriptions at the 5 km intersects.

Despite atrocious weather conditions with low cloud restricting the visibility so essential to this survey and, at the start of the field season, late-melting snow making already difficult hill roads impossible, good progress has been made. Approximately 12 000 km² have been surveyed to mid-September as reported in the following area accounts. This figure would have been greater had the long-awaited new Land-Rovers been delivered and unexpected difficulties over recruitment not encountered.

Although other activities have necessarily been curtailed, four special surveys were carried out and some progress made with land use capability classification, particularly on the sub-division of Class 3 in the North-east.

During the year the Soil Survey lost the services of Mr J. M. Ragg after 28 years, and Mr N. A. Duncan. Three new surveyors were appointed Mr T. W. M. Brown, Mr J. Corbett and Mr A. J. Nolan. With the departure of the Edinburgh staff it was decided, with some reluctance, to close the Edinburgh Survey Office, for the time being. The contact with the East of Scotland College will be maintained through the Perth Office. 801, 802, 804

1:250 000 Survey. Sheet 1 (Orkney and Shetland)

Survey this year was concentrated on Shetland and work on the 1:250 000 soil, associated vegetation, and Land Use Capability surveys was begun. Approximately 1100 km² were surveyed on the Mainland of Shetland and on the isles of Yell and Unst.

The soils of a number of established associations, Strichen, Countesswells, Leslie, Corriebreck, Foudland, Durnhill and Fraserburgh were encountered and three new soil associations were established provisionally.

1. Esha Ness Association: drift derived from granite and rhyolite with andesite, andesitic tuff and some basalt.
2. Sandwick Association: drift derived from flagstones, sandstones and breccias of the Middle Old Red Sandstone with acid schistose rocks.
3. Walls Association: drift derived from sandstones of the Middle Old Red Sandstone with subordinate acid schistose rocks.

The mapping units in each association are complexes of major soil subgroups, each associated with a particular topography. The landscape of Shetland is dominated by peat with peaty gleyed podzols, peaty gleys and ranker soils while magnesian brown soils, alpine podzols, subalpine podzols and gleys, magnesian gleys, noncalcareous gleys and soils of the Fraserburgh Association are of limited and local extent. Vegetation is predominantly moorland, the most common communities being Northern blanket bog, moist Atlantic heather moor and moist Boreal heather moor. The herb-rich Atlantic heather moor vegetation supported by the soils of the Leslie Association on Unst perhaps merits special mention. Grassland is usually pasture but heath *Nardus* grassland is widespread.

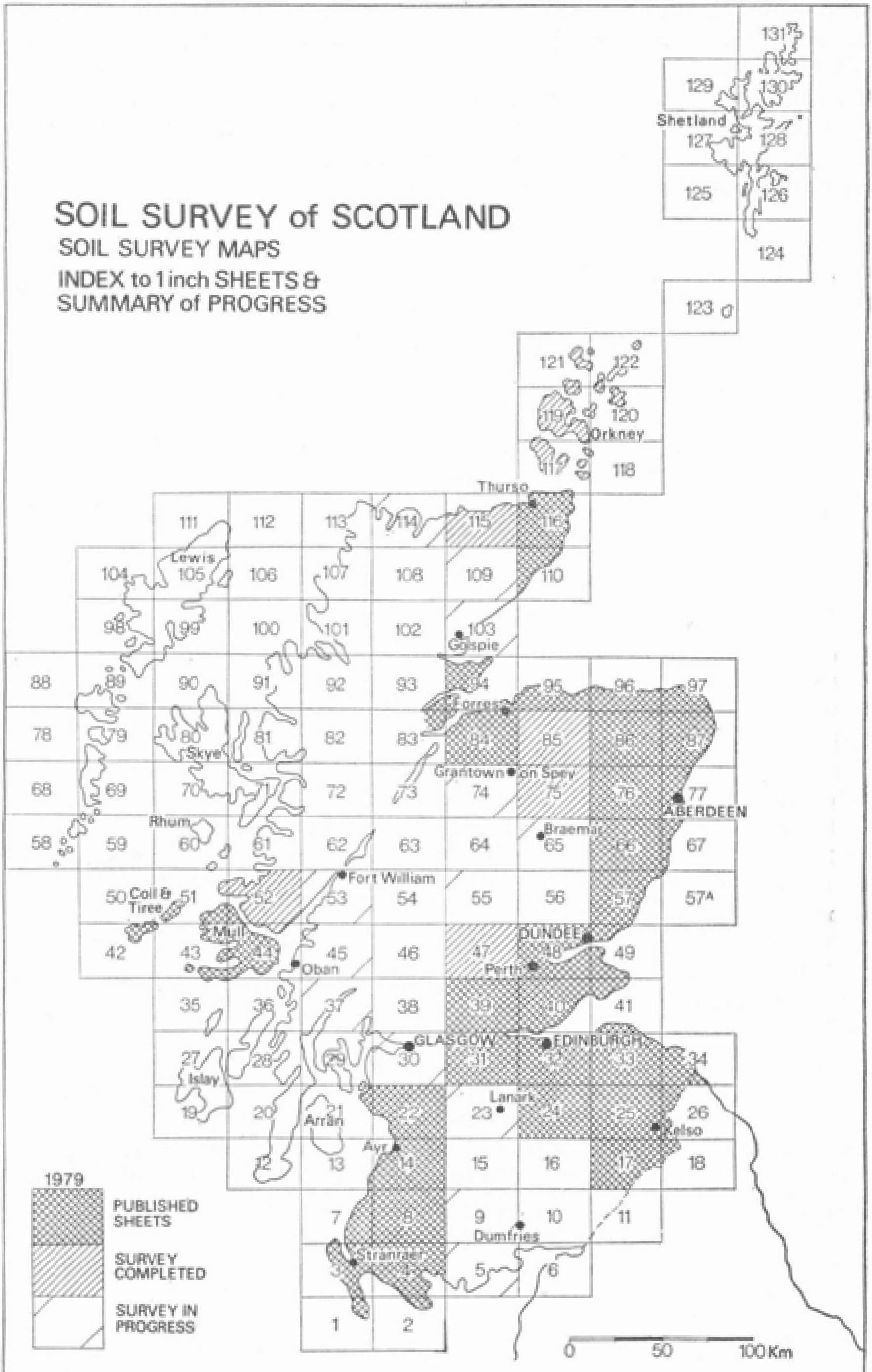
Soils of the Strichen Association dominate the eastern Mainland of Shetland and Yell with peat the dominant soil developed on a gently or moderately rolling landscape. Soil complexes of peat, peaty gleyed podzol and peaty gleys are distinguished on both non-rocky and rocky steep hill-slopes while a similar assemblage of soils was also mapped on strongly undulating rocky ground. A further complex, largely differentiated by the absence of peat, also occurs on rocky undulating terrain. Soils developed on parent material derived from granite and granophyre with some diorite (Countesswells Association) occur most extensively on the western Mainland extending from Muckle Roe to North Roe. The landscape is generally strongly undulating with marked rocky ridges and knolls with peaty gleyed podzols, peaty gleys, ranker soils and peat hollows and channels. Peat develops extensively on a gently or moderately rolling landscape. Subalpine podzols occur widely on Ronas Hill, extending down to approximately 150 metres.

Soils of the Leslie and Corriebreck Associations have been mapped on Unst on gently undulating terrain and rocky hill-slopes. Magnesian gleys dominate the associations while magnesian brown soils are of limited and local extent. Soils of the Leslie Association with profile characteristics akin to those of peaty gleyed podzols with an ill-defined thin iron pan were encountered locally.

Soils developed on drift derived from phyllitic schists with some metagabbro (Foudland Association) occur on the Mu Ness peninsula of south-east Unst on a level or gently undulating landscape. The association is dominated by peaty gleys with subordinate peaty gleyed podzols.

The provisionally named Walls Association occurs most extensively on the Walls peninsula of western Shetland. The soils of the association, peaty gleyed podzols, peaty gleys and ranker soils, occupy a rugged, strongly undulating landscape with rocky ridges and knolls and weakly stepped hill-slopes. Areas of peat occur in intervening flats and channels. Soils of the Sandwick Association have been mapped along the eastern seaboard of the Shetland Mainland on a gently undulating landscape dominated by gley soils.

The Esha Ness Association is confined to the Esha Ness peninsula; the soils, dominantly peaty gleys with rankers and intervening peat, occupy an undulating, weakly-ridged landscape. Rocky basaltic knolls support a rich bent-fescue grassland.


SOIL SURVEY of SCOTLAND
SOIL SURVEY MAPS
INDEX to 1 inch SHEETS & SUMMARY of PROGRESS
Shetland
Orkney
Thurso
Lewis
Golspie
Forres
Skye
Grantown on Spey
ABERDEEN
Rhum
Braemar
Fort William
Coll & Tiree
Mull
DUNDEE
Oban
Perth
GLASGOW
EDINBURGH
Islay
Lanark
Arran
Kelso
Ayr
Dumfries
Stranraer
1979
PUBLISHED SHEETS
SURVEY COMPLETED
SURVEY IN PROGRESS
0
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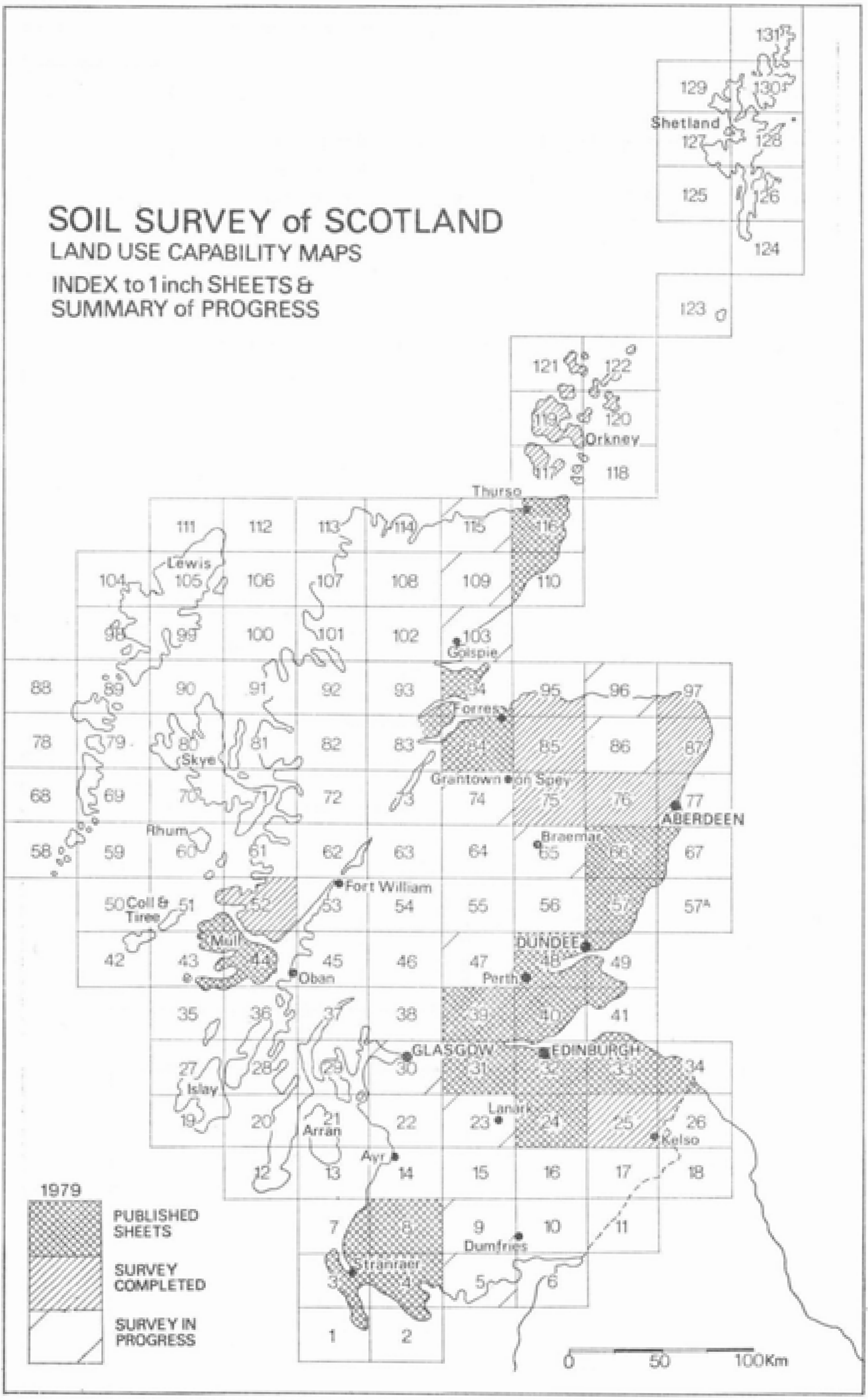
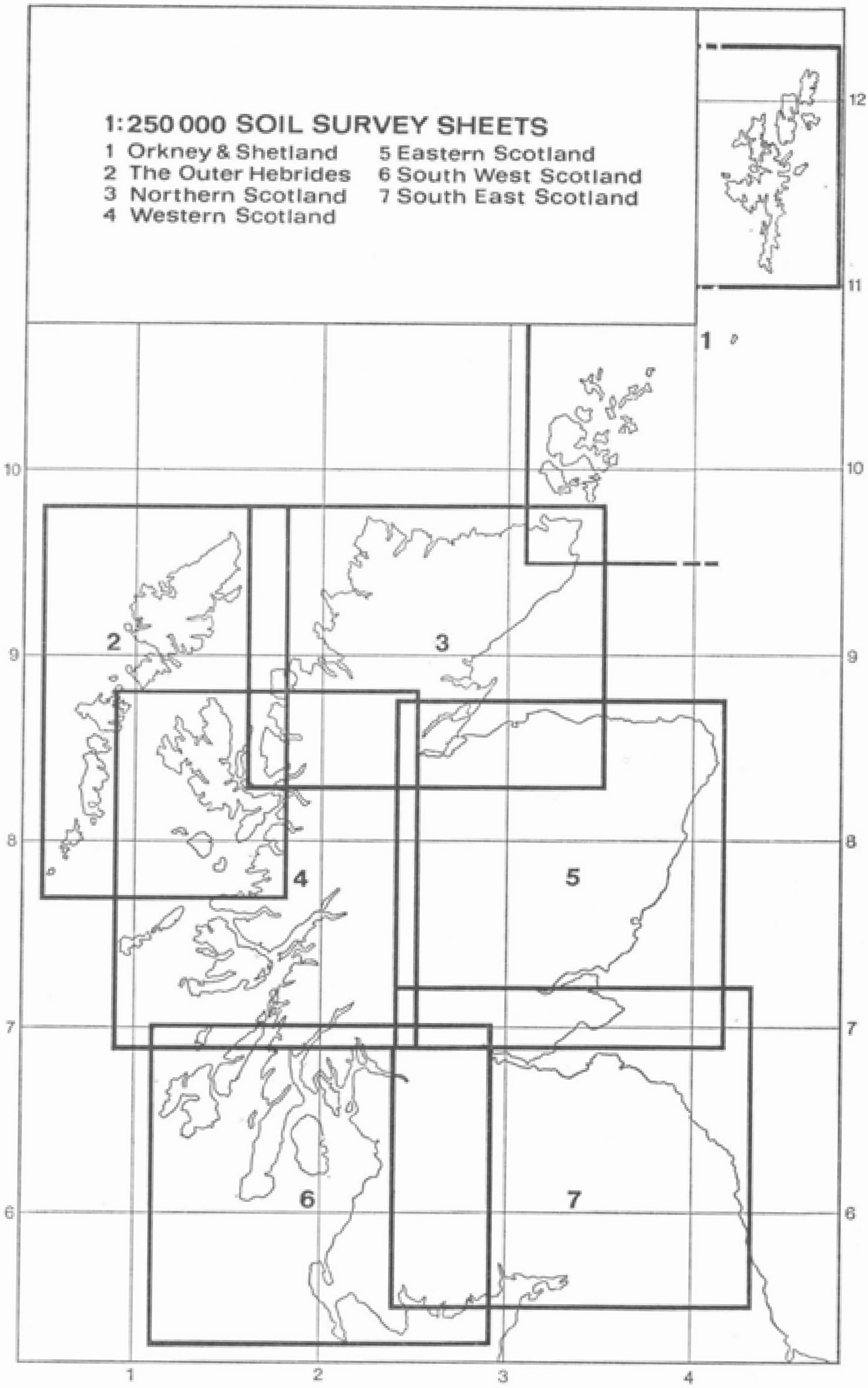

SOIL SURVEY of SCOTLAND
LAND USE CAPABILITY MAPS
INDEX to 1 inch SHEETS &
SUMMARY of PROGRESS
1979
PUBLISHED SHEETS
SURVEY COMPLETED
SURVEY IN PROGRESS
Shetland
Orkney
Thurso
Lewis
Golspie
Forres
Skye
Grantown on Spey
ABERDEEN
Rhum
Braemar
Fort William
Coll & Tiree
Mull
DUNDEE
Oban
Perth
GLASGOW
EDINBURGH
Islay
Lanark
Arran
Kelso
Ayr
Dumfries
Stranraer
0
50
100Km


1:250 000 SOIL SURVEY SHEETS
1 Orkney & Shetland
2 The Outer Hebrides
3 Northern Scotland
4 Western Scotland
5 Eastern Scotland
6 South West Scotland
7 South East Scotland
1
2
3
4
5
6
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12
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Soils of the Durnhill Association are of very minor extent. An area of subalpine podzol occurs on the Hill of Arisdale on Yell and a limited area of peaty podzol, peat and rock complex is found north of Virdi Water on Stang Hill again on Yell.

Areas of wind-blown shelly sand (Fraserburgh Association) are found locally and generally inextensively, the largest expanse occurring around the Bay of Quendale in south Shetland.

The rigours of climate determine that no soil can be in a higher land use capability class than Class 4. The areas of Class 4 land are limited being generally associated with soils of the Sandwick and Leslie Associations and those soils influenced by wind-blown shelly sand or by a limestone or calc-silicate component in the drift. Less specifically, Class 4 land is recognised on non-rocky, moderate hill-slopes supporting thin peat or peaty-topped soils. Most of the area may be classified as belonging to land use capability Classes 5 and 6; the most exposed areas, the areas of subalpine podzol, very rocky hill-slopes and areas of strongly eroded peat may be considered as Class 7 land.

Twenty-seven profiles were described in accordance with the systematic 5 km grid sampling programme. 801

1:250 000 Survey. Sheet 3 (Northern Scotland)

The area surveyed lies between Kylesku, Ullapool, the Dornoch Firth and Ben Klibreck, and covers about 2300 km^2.

A preliminary air photo interpretation of the area was made in which the soil associations and mapping units likely to be present were identified and delineated. The fieldwork then consisted of checking the interpretation and collecting descriptions of soil, site and vegetation. In addition, soil profiles were described at every 5 km intersect of the National Grid and described and sampled at every 10 km intersect to provide data for the Soil Inventory.

The soil parent materials are predominantly stony and coarse or moderately coarse-textured, the soils mostly shallow and deep peat, peaty gleys and peaty gleyed podzols, and the landscape mainly rocky in the west and non-rocky in the east. The most common vegetation communities are blanket bog, bog heather moor and their northern equivalents, with moist and Northern Atlantic heather moor more common in the south-eastern part of the area.

In the western part of the area the soils belong mainly to the Lochinver Association, developed on parent materials derived from Lewisian rocks, and the Torridon Association, on parent materials derived from Torridonian rocks. The predominant mapping unit of the Lochinver Association is a complex of shallow and deep peat, peaty gleys and peaty rankers on strongly rolling, rocky landscape. In the Torridon Association the main mapping units are a complex of shallow and deep peat and peaty rankers on rocky, rolling or stepped topography, and a complex of skeletal soils and oroarctic soils on steep rocky hills.

A narrow band of Cambrian quartzites and limestones lying between Loch Glencoul and Loch Broom give rise to soils of the Durnhill and

Inchnadamph Associations respectively. The two main complexes in the Durnhill Association are peat and peaty soils on rocky, rolling landscape, and skeletal soils and oroarctic soils on rocky and stony hills. The Inchnadamph Association includes only two complexes; the most widespread is one of brown rendzinas on limestone ridges, with deep peat and peaty gleyed podzols and the other a complex of brown rendzinas and brown forest soils.

Soils of the Strichen Association, developed on parent materials derived from Moinian rocks, predominate in the central and eastern parts of the area, the most widespread map units being complexes of peat and peaty gleys on gently rolling non-rocky moorland, peat and peaty gleyed podzols in areas of hummocky drift, and peat, peaty gleys and peaty rankers on rocky ground.

The granite areas of Migdale and Rogart have soils of the Countesswells Association, the most common map unit being a complex of peat and peaty soils on non-rocky land.

Peat is extensive, particularly in the central and eastern part of the area. Three maps units have been identified, namely, undifferentiated peat, deep peat and eroding peat. 801

1:250 000 Survey. Sheet 4 (Western Scotland)

The major project undertaken in the West Scotland region continues to be the 1:250 000 soil map programme. Despite poor weather with severe conditions and protracted snow cover at low levels in the mountains until well into May followed by a rainy summer, steady progress has been maintained. A total of 3400 km^2 (1313 square miles) has been surveyed during the year brining the area surveyed in the region to 8900 km^2 (3436 square miles) out of a total of 14 300 km^2 (5521 square miles). Of the 44 profiles taken for analysis, 34 were at 10 km intersects of the National Grid as part of the national soil inventory and 10 illustrated soils limited in extent, but of agricultural importance. Also, as part of the soil inventory, 102 profile descriptions have been recorded at 5 km intersects.

During late 1978 the survey was concentrated in the hills south of Crianlarich and Tyndrum. In early 1979 the south-western end of the Great Glen was examined, followed by the area between the " Roads to the Isles," that is north of the Fort William to Mallaig, but south of the Invergarry to Kyle of Lochalsh routes. The peninsula between Kyle of Lochalsh and Loch Carron and the inaccessible areas between Kintail and Glen Affric were also mapped.

Much of the land surveyed falls into mapping units previously recognised, particularly on the Moine schists, or on related units on other soil parent materials. The salient features during the year have been the striking difference in the distribution of mineral soils on basic igneous rocks, limestones or on slightly richer rock types within the Moine series or the Lewisian (e.g those higher in hornblende). The glacio-lacustrine sediments of Glen Roy were also distinctive. The quartzites of eastern Islay and Jura (Sheet 6) give little parent material for mineral soils, but the Isle of Islay has some interesting tills and fluvioglacial deposits upon which the principal agricultural areas are located. As may be expected, the amount of podzolic soil increases towards the east of the region, but few clearly defined areas dominated by podzols have been mapped.

South-west Inverness-shire, Loch Carron to Fort William. The dominant parent materials of the region are glacial drifts formed from psammitic and pelitic schists and gneisses of Moine age. These drifts are stony sandy loam or loamy sand in texture and are mapped within the Moine " phase " of Strichen Association, which differs in texture from the Dalradian " phase " of Strichen in South Argyll. No detailed Geological Survey maps were available for much of the area, but a 5 km broad belt of micaceous schist was encountered during the survey which runs north from Glen Quoich, crosses Glen Shiel at the Cluanie Inn and continues towards upper Glen Affric. This rock is more easily weathered than the surrounding schists and map units are characteristically less rocky, with a greater proportion of colluvial drift. The vegetation is *Nardus* and *Molinia* grasslands, in contrast to the *Molinia* grasslands and wet heaths of the coarser schists.

The dominant soils encountered throughout the region were peaty gleys, peat and minor peaty podzols. Brown podzols, humus iron podzols and low humic gleys, subalpine and alpine soils, were very restricted.

The map units used to accommodate soils of the Strichen Association were similar to those of Sheets 51 and 52 (Ardnamurchan). Rock-dominated peaty complexes are widespread in the south-west of this area, between Arisaig and a line from Glenfinnan to Glen Quoich. Hummocky moraines and moderately rocky ground become extensive in the east and large areas of Strathnaver complex have been mapped in Glen Garry. Peaty podzols occur more frequently near the eastern perimeter around the Great Glen and small areas of a peaty podzol complex have been mapped above Loch Lochy and the River Lochy.

The Lewisian rocks around Glenelg and Kirkton of Lochalsh consist of hornblende-gneiss, biotite-gneiss, garnet-kyanite-gneiss, garnet-amphibolite and eclogite. These rock types weather to form a less acid parent material which has been mapped provisionally within the Tarves Association. The soil complexes were similar to those of the Strichen Association, but the distribution pattern is markedly different, with brown podzolic soils more widespread on the Lewisian drifts.

Small outcrops of intermediate and basic igneous rocks occur at Ratagan, Glen Loy, Glen Dessary and Clunes. The diorite and basic syenite of Ratagan, the mafic metasyenite of Glen Dessary and the tonalite of Clunes have been provisionally included in the Tarves Association, while the hornblende-gabbro of Glen Loy was included with the Insch Association.

The sands and gravels of the outwash and raised beaches are restricted in extent, but form the main agricultural and crofting land of the area. The soils are mapped in Corby and Boyndie Associations, and the main areas are at Arisaig and Kirkton of Lochalsh, with smaller areas dotted along the coastline and around the shores of lochs. The fluvioglacial deposits of Glen Roy, Glen Gloy and lower Glen Spean give very variable parent materials ranging from coarse clay to coarse sand. The soils are principally humic and peaty gleys.

Crianlarich-Glen Fyne. The mountainous area south of A82 Crianlarich-Dalmally is principally composed of quartz-mica schists of Dalradian age. The typical sequence of hummocky valley-bottom moraine, followed by steep moraine and colluvium on valley sides and frost shattered debris on mountain summits is well displayed. The principal soils are peaty gleys and peaty gleyed podzols with extensive peat in valley bottoms and on hill summits. Mineral soils are infrequent. Although principally included in the Strichen Association (Dalradian phase) some hornblende rich areas in Glen Cononish suggest Tarves Association. The moundy topography at the confluence of the rivers Cononish and Fillan has been mapped as the Tuttach complex of the Corby Association. 801

1:250 000 Survey. Sheet 5 (Eastern Scotland)

Inverness-shire. Reasonable progress has been maintained with the 1:250 000 mapping project despite the initial severe weather conditions when access to the plateaux was restricted by late-lying snow. Access to these areas was further restricted during the grouse and deer-stalking seasons. Lack of suitable geological maps over most of the region has also tended to impede the rate of work. Mapping was concentrated in two main districts.

The first area lies in a belt stretching from Gleann Einich in the north-east to Loch Treig in the south-west. Bounded to the north by the River Spey and to the south by the Highland-Tayside Regional Boundary, it is underlain by rocks of the Moinian Assemblage with major instrusions of granites. Most of the soils have been mapped within the Strichen, Countesswells and Aberlour Association, together with their rock-associated complexes, e.g. Glentarroch, Aittendow, Kingairloch and Avon. A feature of the landscape is the apparent constant division into depositional and erosional facets. The former occupies extensive embayments within the valleys and along the edges of the plateaux. The thickness of the till in such locations may exceed 30 metres. Above such depositions most of the soils are formed in a thin veneer of locally derived drift, commonly less than 1 metre thick. An altitudinal succession of iron-humus, peaty, peaty-gleyed, sub-alpine and alpine podzols is characteristic of the whole region. Usually the peat is between 2 to 3 metres and is extensively hagged.

Widespread across the Gaick Plateau is the occurrence of deeply weathered grey gneisses up to 12 metres thick. The derived soil is usually a subalpine podzol, even at a height of 1000 metres, and supports a distinctive *Carex-Empetrum-Vaccinium* vegetation. Such areas provide renowned summering for sheep. Also noticeable across the whole region is the increasing presence of *Molinia caerulea* along an east-west transect, accompanied by an increasing rainfall. Perhaps aided by grazing pressures, there is an apparent replacement of *Calluna vulgaris* by *Molinia* within the iron-humus and peaty podzol zones. Thus, in the vicinity of Loch Treig, the moundy moraines of the Sanda and Strathnaver complexes are completely dominated by *Molinia caerulea* and *Eriophorum vaginatum* whether the soil is a podzol on the crests of the mounds or a gley in the hollows.

The second district stretches from Inverness to Dunmaglass in the south-west. Whereas most of Strathnairn is also underlain by rocks of the Moinian Assemblage and associated granites, the area to the north-west is underlain by sediments of Middle Old Red Sandstone age. From Daviot to Loch Duntelchaig the soils are mainly derived from grey flaggy sandstones with minor areas of greenish shales and have been mapped within the Kindeace and Mount Eagle Associations and the Drummossie complex. South-west of Erichte, however, more resistant breccias, conglomerates and arkoses have formed a contrasting and rugged topography. There the derived soils are either residual or colluvial with frequent stabilised or loose screes. Such soils have been provisionally placed within a new complex, the Farigaig complex.

Aberdeenshire and Angus. Soil and land use capability mapping for publication at the 1:250 000 scale has been carried out in areas of one-inch Sheets 65 (Balmoral) and 64 (Kingussie) and approximately 500 km^2 have been surveyed. Mapping of Sheet 65 has now been completed. The areas surveyed include the upper parts of Glens Callater, Tanar, Shee, Isla, Prosen, Clova and Esk. Ten profiles were described and sampled for analysis. The majority of the profiles were systematically located at 10 km grid intersections.

Soils of the Strichen Association are the most extensive. They are more widespread than had been expected, because in the Angus glens most soils formed from foliated micaceous gneiss and its derived drifts do not have the gritty textures characteristic of the Aberlour and Countesswells Associations, and those formed from quartz-schist and its derived drifts do not belong to the Durnhill Association. Soils of the Tarves Association have been mapped on mixed drifts derived from acid and basic rocks and on diorite, hornblende schist and other rocks of intermediate basicity. Soils of the Countesswells, Durnhill and Foudland Associations have also been distinguished. Peat is a constituent of a number of mapping units and where it is extensive, for example, at the head of Glen Esk, it has been mapped separately. In Glen Clova fluvioglacial gravels with interbedded sands form soils of the Corby Association. The proportion of basic material is higher than the average for parent materials of the association, and it is probable that this is mainly responsible for the prevalence of brown forest soils rather than the usual podzols. It will not be possible to show the association separately on the published map, but a mapping unit comprising the Corby Association and alluvium has been distinguished.

Nearly all the land has been rated as no better than Class 6, the major limitations being climate, soil wetness, slope, and the presence of rock outcrops and boulders. Within Class 6 there are considerable differences in grazing value, the best grazing occurring on the mineral soils of the Tarves, Strichen and Foudland Associations and the worst on the dystrophic peats. The plant communities on the mineral soils include tussock-grass pasture (restricted to the Tarves Association), bent-fescue grassland and sharp-flowered rush pasture. On subalpine soils forestry is precluded because of the exposure, but the upland bent-fescue grassland provides good grazing. Locally, for example in Glen Callater, this community includes meadow grass, *Poa pratensis*, which has a high grazing value.

Perthshire. Work on the production of 1:250 000 soil and land use capability maps has been continued within two distinct and contrasting areas of the Central Highlands. Provisional mapping units, which are based on soil parent material, major soil subgroups and topographic characteristics, have been established and correlated along the extreme northern boundary of the area allocated to the Perth office. During the course of the survey, 38 profiles were exposed by the Smalley excavator and 49 profiles described in connection with the proposed Soil Inventory of Scotland. Of the latter profiles 16 were sampled.

The greater part of the mapping was done in the area between the A9 trunk road and Rannoch Moor and stretching between the northernmost edges of Sheets 47 (Crieff) and 46 (Balquhidder) and the lochs of Rannoch and Tummel. Most of the area is underlain by rocks of the Dalradian and the Moinian series of Highland schist, which form the parent material of the Strichen Association. In general, the soils developed on the former are more base-rich than those of the latter rock type, on the evidence of the overall vegetation cover and, in particular, the presence of base-rich plant indicators. The derived drift is stony and coarse textured. Within the broad valleys of the rivers Tay and Tummel the drift has often been modified by the action of water in post glacial times. In summit positions and on some upper convex slopes the drift is shallow and usually overlies shattered rock. Dark fine-grained schists are prevalent around Dunkeld and north of Loch Tummel and soils of the Foudland Association are formed on the rocks and their derived drift. However, the areal extent of the Foudland Association is so small that it may be impossible to map its distribution at the 1:250 000 scale. Similarly, in the high ground north and south of Aberfeldy, numerous outcrops of hornblende schist and epidiorite only locally affect the drift which remains dominantly schistose (Strichen Association). The areas of such outcrops are conspicuous by possessing a much richer and varied vegetation cover and a high proportion of previously cultivated soils in those parts now managed as a grouse moor. Limestone soils, provisionally grouped within the Deecastle Association, are to be found around Tulach Hill (NN 860640) and in the foothills of Schiehallion. Most of Rannoch Moor is underlain by granite, which forms the parent material of soils belonging to the Countesswells Association.

In valley situations brown podzolic soils, iron-humus podzols, non-calcareous gleys and peaty gleys are dominant. Above about 300 m, peaty podzols, peaty gleys, peaty rankers and peat are to be found. At high elevations the soil pattern is dominated by extensive hill peat which varies in depth from 1·5 to 3·0 m and which often displays a distinctive erosional pattern of dendritic and linear hagging, together with subalpine podzols, alpine soils and rankers.

The topographic characteristics associated with the mapping unit largely depend on whether the agencies of glacial erosion or deposition have been active. On the high ground, mapping units similar in concept to the Glentarroch, Aittendow and Assapol complexes have been identified. New units will be introduced for the long, low angle, non-rocky slopes of valley and till-filled embayment situations and also for the steep rocky slopes on which colluviation is an important feature. The latter unit is best illustrated along Loch Tummel and within the Tay valley. The rich arable lands associated with the River Tay alluvium are of such narrow extent that they will have to be combined with the adjoining fluvioglacial terraces (Corby Association) to produce a satisfactory 1:250 000 mapping unit. The rugged terrain between Glen Lyon and Loch Rannoch and around Farragon Hill is generally dominated by rock outcrop and mapping units to accommodate high elevation soils, peat and rock outcrop have been identified. In some instances the extremely steep terrain, e.g. high corrie walls, has made it difficult to delineate some readily identifiable topographic units as discrete entities.

The second survey area extends between the old Aberdeenshire-Perthshire boundary and the A9 trunk road. It is extensively grouse moor and deer forest with some poor quality arable land along the major valleys and is virtually devoid of planted or natural forest. The soils are mainly derived from acid schists of the Moinian Assemblage (Strichen Association), although soils of the Countesswells, Tarves, Dulsie and Corby Associations have also been identified. A mixed drift derived from granite and acid schists, the soil parent material of the Aberlour Association also occurs but cannot be mapped at the scale of 1:250 000. Limestone and quartzite derived soils (Dee castle and Durnhill Association respectively) are both confined to Glen Tilt where they are of small areal extent.

The soils are predominantly peaty podzols and peaty gleys, while deep blanket peat not only forms a major constituent of many mapping units but also is often sufficiently extensive to be mapped separately. In localities where the peat is deeply hagged, the thin iron pan of an underlying peaty gleyed podzol is sometimes exposed. Above about 570 m the most extensive soils are subalpine podzols, alpine soils and rankers with deep hagged peat also present in significant amounts.

At high elevation, most of the mapping units have been correlated with those already in existence. However, a new unit will include non-rocky, exposed hill summits with subalpine soils and deep peat, the latter confined to col and depressed sites. A further unit consisting of shallow peat and peaty gley, but with no rock outcrop, may be recognised on steep slopes immediately below broad expanses of hill peat. The dominant mapping units associated with the moundy moraines to be found within valley sites correlate with the Strathnaver complex and the Dalvina complex of the Strichen Association. Instances of the Rhilean complex (Dulsie Association) have been recorded. Where steeper sided moraines have been identified, they have been mapped as belonging to the Tuttach complex, a complex of the Corby Association in which peaty podzols (Tarbothill series) occur within peat.

Fieldwork has been completed in the Glen Lyon area of Perthshire to link Sheet 47 to the south with the Rannoch and Atholl areas to the north and north-east. The majority of the soils belong to the Strichen Association and mapping units have been set up to link soils with topography and vegetation.

Line traces have been prepared of the following soil maps and provisional mapping units have been delineated for use at the quarter-million scale:

Sheets 76/77 (Inverurie, Aberdeen), 48/49 (Perth, Arbroath),

39 (Stirling) and 40 with parts 41 and 32 (Kinross, Elie).

This work is being continued on other soil maps in East Scotland already published at the 1:63 360 scale. 801

1:250 000 Survey. Sheet 6 (South-West Scotland)

Jura. The Island of Jura is predominantly quartzite (Durnhill Association). Apart from some area of drift cover, the topography is rocky. Peaty podzols and peaty rankers with a dense *Calluna* cover are present on steep slopes, but are replaced by peaty gleys and peat on lower slopes. The terrain is more subdued on east and west coasts where glacial till and raised beaches are found, but extensive peat cover and very bouldery soils make much of the land uncultivable. Arable land is confined to a few areas of more sandy raised beach (Corby Association) and to the black schist in the south-east of the island (Foudland Association).

Islay. The quartzites of north and east Islay give rise to similar soil sequences to the quartzites of Jura. The Lewisian gneiss and Torridonian phyllites, grits and arkoses also give rise to rugged topography with extensive organo-mineral and organic soils. The Dalradian limestones have shallow soils with mineral or humose mineral surface horizons and free or imperfect drainage while the phyllites of similar age also have shallow soils, but with poorer drainage and more humose topsoils.

Islay is more extensively drift-covered than Jura. The striking feature of its tills is that they are rarely derived from local strata although its influence may be detected in the stone content. The till appears to have three main provenances, (a) the south and east has a brick red till of sandy loam texture possibly derived from Old Red Sandstone rocks, (b) the north and west between Bridgend and Sanaigmore has a yellow brown sandy loam indurated till and approaches nearest to a locally derived till although some red sandstone influence is detectable, (c) the drumlinoid areas of the Rhinns of Islay have red-brown clay loam and clay tills with strong similarities to some of the tills of Ayrshire and the Lothians produced from Carboniferous rocks.

Water modification of the tills has occurred by fluvioglacial processes (beaded eskers and terrace deposits are common), and by the action of the sea. Below the 15 m contour the soils are derived from well sorted sand and gravel. Between 15 m and 30 m the deposits are very variable water-modified tills with some gravel areas. Above the 30 m contour the degree of water modification depends on the configuration of the ground and the proximity of major fluvioglacial drainage channels. Dune sands are developed along the west and north coasts.

The cultivated lands have a wide variety of soil types, but the arable land is associated with the till and raised beaches, while grasslands are established on shallower soils or those with induration.

The till soils and limestones have not yet been allocated to an association but the remainder of the soils fit into previously described associations (Strichen, Torridon, Foudland, Corby, Boyndie) and mapping units.

Fieldwork has been completed in Lanarkshire immediately north of the Southern Upland Boundary Fault to fill in gaps in the partly surveyed Sheet 23 (Hamilton). The area is complex geologically, including rocks of Silurian, Downtonian, Old Red Sandstone and Carboniferous age and the drifts derived from them form a complex admixture of soil parent materials. For small scale mapping they can conveniently be divided into mapping units based on the Ettrick, Glenalmond, Sourhope, Sorn, Rowanhill, Kilmarnock, Darleith and Darvel Associations. The very high rainfall results in extensive areas of peat and peaty gley soils and these have been separated wherever practicable.

The area of the Clyde Plateau Basalts both north and south of the Clyde estuary has been briefly examined and mapping units based on the Darleith Association have been formulated. Much of the work delineating these will be done using aerial photographs, with a rapid ground check round the margins to complete this area. Similar work is in progress for the Upper Forth Valley around Aberfoyle. 801

1:250 000 Survey. Sheet 7 (South-East Scotland)

Survey has been continued this season in two areas in the detail appropriate for the compilation of maps at the scale 1:250 000. At Langholm between the Ewes Water and the English border 400 km^2 have been surveyed and further north an area of 100 km^2 north and east of Moffat have been mapped. Thirty-six profiles from the area between Dumfries and Canonbie have been described and sampled.

At Langholm, east of the Ewes Water, the outcrop of sedimentary rocks, mainly sandstones of the Carboniferous Limestone Series is extensive, slopes are mainly moderate or gentle and a grey sandy clay loam till derived from the underlying strata is the principal soil parent material. Gley soils of the Carter Association predominate with the noncalcareous gley, Letham series, on the lower slopes and the peaty gley, Carter series, on the middle and upper slopes. On some steep ground with shallow drifts, map units, including the peaty podzol Arks series, have been distinguished. A few small outcrops of basaltic lavas with shallow stony drifts carry peaty podzols and brown forest soils of the Darleith Association. Map units of the Minto Association have been delineated in a small area where the soil parent materials are drifts derived from a mixture of greywackes and shales, red sandstones and some lavas.

In the Moffat area, greywackes and shales of the Ordovician and Silurian Systems outcrop over almost the entire area and the soil parent materials are the loam drifts and clay loam tills derived from these strata. The topography is predominantly that typical of the Southern Uplands, smooth rounded hills with steeply sloping sides, but in the upper parts of the valleys of the River Tweed, the Borthwick Water and the River Teviot, the hills are smaller with moderate and gentle slopes. On the higher hills, over 600 metres in altitude, the subalpine soils of the Merrick series are extensive. Below 600 metres on steep slopes, the peaty podzols and podzols of the Dod and Minchmoor series predominate and on the lower slopes and footslopes the brown forest soil Linhope series, and the noncalcareous gley Ettrick series, predominate. In the upper reaches of the valleys map units comprising peaty gley and noncalcareous gley soils have been delineated on account of the contrast in character with the surrounding podzols.

In areas where the hills are smaller and steep slopes less extensive, units comprising peaty podzols, peaty gleys and peat have been mapped. At moderate altitudes areas with irregular topography and varied soil pattern have also been distinguished, mainly south of Kinnelhead and between the White and Black Esk rivers.

Throughout much of the country surveyed this season in the Southern Uplands the soil pattern is such that individual series can be readily delineated at the one inch to one mile scale, but map units suitable to the 1:250 000 scale having a distinctive character are much less easily defined.
801

1:63 360 Survey. Sheet 47 (Crieff)

The survey of Sheet 47 has been concluded with the final correlation of approximately 30 km² (12 square miles) of ground in and around Glen Lednock some two miles north-west of Comrie. The area includes a large underlying basic instrusive igneous mass which contributes to the drift from which the overlying soils are developed. The more basic soils have been included in the Insch Association and correlate fairly well with the type areas in Aberdeenshire where they were first described. Other soils re-examined were assigned to the Aberlour, Darleith, Foudland, Nochty and Strichen Associations. 801

Land Use Capability Survey. Sheet 87/97 (Peterhead/Fraserburgh)

Class 3 land, which covers approximately 80% of the area, has now been assigned to one of three sub-divisions using gradient, climate, soil wetness, soil depth, stoniness and estimated crop yields as criteria. Amendments to draft maps were made following consulations with the Department of Agriculture and Fisheries for Scotland and the North of Scotland College of Agriculture. The most extensive areas of sub-division 1 occur on the imperfectly drained Thistlyhill series of the Tarves Association. The freely drained Tarves series is usually too stony or has an indurated layer within 40 cm of the surface. Other areas of sub-division 1 are found on Foudland series (Foudland Association), Baikies series (Strichen Association) and Auchiries series (North Mormond Association). 801

Special Surveys

Gretna to Annan Road Re-alignment, Dumfriesshire. At the request of the Scottish Development Department, a map was prepared of the main soil and land use capability characteristics of an area of 48 km^2 in which several proposed road re-alignments are being considered.

Glen and Gatehouse of Fleet Road Re-alignments, Kirkcudbrightshire. At the request of the Dumfries and Galloway Regional Council, soil and land use capability maps were provided of areas of 10 km^2 and 17 km^2 respectively where proposed road re-alignments are being considered.

Tullos Hill, Aberdeenshire. At the request of the Scottish Development Agency, a soil map at a scale of 1:5000, with accompanying report, was prepared of this proposed park site. 801

Vegetation Surveys

A final draft of the vegetation map of the Cairnsmore of Fleet area was completed and handed over to the Cartographic Section for reproduction. Further sampling of the *Ranunculus repens - Juncus effusus* community and a few other minor communities was carried out when records of these were found to be inadequate.

The major part of a bulletin comprising revised and additional tables of Scottish plant communities has been prepared. This will provide basic descriptions of a much wider cover of communities than that given in "Plant Communities and Soils of the Lowland and Southern Upland Regions of Scotland."

During the summer of 1979 the vegetation of the Banchory and Stonehaven area (Sheets 66 and 67) and the Forfar area (Sheet 57) was recorded by plant sociological methods to provide an account of the vegetation for a soils memior.

A reconnaissance and intial sampling of the vegetation of the Gairloch area, Wester Ross, was carried out in August and September. The area has been selected for an intensive survey, including a map of the plant communities.

A second draft of the "Key to the Common Plant Communities of Scotland" was prepared on the basis of the previous year's field experience. This Key has been designed to assist the soil surveyor in the recognition of plant communities and it will eventually be published, together with a brief description of each community and its ecological characteristics.

The remit for the 1:250 000 Upland Survey requires that the legend of the agricultural capability maps should give an indication of the grazing value of Class 6 land. Accordingly, a short pamphlet on the "Assessment of Relative Grazing Values of Scottish Grassland and Moorland Communities" has been produced to assist the surveyor in rating such land as "good," "moderate" or "poor" in terms of its present grazing value to sheep.

Fieldwork has continued with visits to all areas involved in the 1:250 000 survey. Vegetation recorded by the Soil Survey teams was correlated with the units devised by the Vegetation Survey and additional phytosociological data for under-recorded and new plant communities were collected for inclusion in and up-dating of the Scottish plant community classification. A simple card has been devised for recording the vegetation and site data of the components of the 1:250 000 soil mapping units and the resulting data bank will be used to establish mapping unit/plant community links for the soil map legends. 802

Soil Micromorphology

There has been a considerable increase in the amount of thin section preparation work during the current year. Some 450 soil thin sections have been prepared, of which approximately 140 are specifically required for the Scottish excursion to follow the 6th International Working Meeting on Soil Micromorphology to be held in London in 1981. A further eight profiles for the same post-conference excursion have been selected and sampled.

Work is continuing on clay mobilization, translocation and deposition within the soil profile. An interesting sideline which has developed after the examination of buried soils from several archaeological sites has been an attempt to identify certain cist of egg case-like objects. These have now been found in soils dating from about 5000 years B.C. to the present day and appear to be associated with agricultural activity.

A paper on the Micromorphology of Young Soils from South-east Iceland[1] has now been accepted for publication. A joint paper (W. J. McHardy and L. Robertson) on Optical and Scanning Electron Microscopy in Soil Micromorphological Studies was presented by Dr W. J. McHardy at the Royal Microscopical Society Meeting on Clays and Soils in Edinburgh. 804

Other Work

Collaboration has continued with the Department of Agriculture and Fisheries for Scotland and with the three Scottish Colleges of Agriculture. This has been mainly concerned with providing soils information to assist in field drainage and reclamation projects, demonstrating soil conditions in the field and the application of guidelines to ensure consistent assessment in land classification. Soil monoliths were provided for a North College exhibit at the Royal Highland Show and for the SARI exhibit at Ingliston.

Liaison with the Forestry Commission included, in addition to field demonstrations, further consultation on the development of a land use capability classification for forestry which is now at an advanced stage. Liaison has also continued with other departments of the Institute, notably with Microbiology on the project to study organisms causing ochre deposits in drains and with Soil Organic Chemistry in their investigation of podzolization.

Requests for soils information for specific areas continue unabated. Assistance has been given to the Highland Regional Council in reviewing their A9 Site Investigation Report and in on-site consultations, to the Royal Scottish Forestry Society, the Aberdeen Institute of Ecology and the Aberdeen University Geography Department with excursions and to the Atomic Energy Authority, Harwell, on the selection of sites for soil sampling in connection with a radio-active fall-out survey.

Papers on the moisture regimes of six soils[3] and on options for direct drilling in Scotland[4] have been published as has a note on land capability evaluation in Scotland[5]. Papers on Scottish mountain and aeolian soils[6], land assessment in Scotland[7] and on land use capability assessment in the Western Highlands[8] have been accepted for publication. 801, 802, 804

The publication of an account of the soils of Sutherland referred to in last year's Report is still awaited[9], but those on the three soil profiles from Elephant Island[10] and the account of the drainage of soils of low permeability on the Slamannan project[11] have now been published.

Maps, Memoirs and Cartography

The one-inch Land Use Capability map for combined Sheet 84/94 (Nairn/Cromarty) has been published.

All future Soil Survey and Land Use Capability maps are to appear in both flat and folded versions; covers have been designed and the relevant artwork for all of the sheets listed below has been delivered to the Ordnance Survey for production of the covers: one-inch Land Use Capability Sheet 57 (Forfar) and combined Sheet 35/36/43/44/51 and 52 (Island of Mull) have been printed and are awaiting folding and casing before publication is announced.

Colour proofs for Soil Survey combined Sheet 85/95 (Rothes/Elgin) have been examined and returned to the Ordnance Survey. In view of the complexity of this sheet and the large amount of amendments required, it has been decided that a second colour proof is necessary. Colour proofs for Soil Survey Sheet Ardnamurchan and Morvern have been received from the Ordnance Survey and are awaiting examination.

The scribed negatives and colour models for the following Land Use Capability sheets have been sent to the Ordnance Survey and colour proofs are awaited: Orkney-Northern Isles, Orkney-Hoy, Ardnamurchan and Morvern, all on the 1:50 000 scale and 25/26 (Kelso/Berwick), 76/77 (Inverurie/Aberdeen), 85/95 (Rothes/Elgin) and 87/97 (Peterhead/Fraserburgh), all on the 1:63 360 scale.

The scribed negatives and colour models for the following Soil Survey sheets have been sent to the Ordnance Survey and colour proofs are awaited: Orkney-Northern Isles and Orkney-Hoy on the 1:50 000 scale and Sheet 75 (Tomintoul) on the 1:63 360 scale.

The following 1:63 360 Soil Survey sheets are being reprinted: 48/49 (Perth and Arbroath), 57 (Forfar), 66/67 (Banchory and Stonehaven). Minor amendments are being incorporated in the soils mapping and changes are being made in the sheet layouts.

A considerable amount of scribing and compilation work has been done on all of the 1:250 000 topographic base maps. Sheet 3 (Northern Scotland) has been selected as a model for developing the specification of the remaining six sheets. Negatives of the components of Sheet 3 have been sent to the Ordnance Survey for further processing and for the manufacture of both plastic and paper proofs. A preliminary assessment of the results to date indicates that the 1:250 000 bases will be printed in two colours. Administrative names and boundaries, National Grid, hill names, spot heights, contours and roads will be printed in various strengths of dark grey. The coastline, rivers, lochs, sea and all drainage names will be printed using a blue which does not clash with either of the blues which are to be used in the overprinting of the soils and land use capability information.

All of the backlog of cartographic work on 1:63 360 land use capability work has now been cleared and most of the department's cartographic resources in the next year will be devoted to the production of the remaining six 1:250 000 base maps.

The following limited circulation maps have been prepared: soils and land use capability of The Glen and Gatehouse of Fleet areas, Dumfries and Galloway, the Annan-Gretna A75 Bypass, all on the 1:25 000 scale, The Soils of Tullos Hill on the 1:5000 scale, The Soils of Clinterty College Farms on the 1:10 560 scale and the land use capability of areas around Ardnamurchan and Sunart on the 1:50 000 scale.

Work has been suspended meantime on the production of 1:25 000 scale Soil Survey field sheets for restricted circulation, the total available at present stands at 153. No further work will be done on this scale until after the completion of the 1:250 000 sheets.

The second Assessment of Climatic Conditions in Scotland map on the 1:625 000 scale, based on exposure and accumulated frost, is being reprinted.

The memoir to accompany Sheets 1, 2, 3 and 4, The Soils of the Country round Stranraer and Wigtown, has been printed and publication is expected by the end of the year[2]. 801

References:

1. The micromorphology of young soils from South-east Iceland. By J. C. C. Romans, L. Robertson and D. L. Dent (University of East Anglia). To be published in *Geografiska Annaler*.
2. The soils of the country round Stranraer and Wigtown. By C. J. Bown and R. E. F. Heslop. With an account of the vegetation by E. L. Birse and J. S. Robertson. To appear in *Mem. Soil Surv. Gt. Br.*, Macaulay Institute for Soil Research, 1979.
3. The moisture regimes of six soils in the Central Lowlands of Scotland. By N. A. Duncan, *J. Soil Sci.*, **30**, 215-223, 1979.
4. Soil, climatic and management options for direct drilling cereals in Scotland. By J. D. Pigeon (SIAE) and J. M. Ragg, *Outlook on Agric.*, **10**, 49-55, 1979.
5. An evaluation of the land use capability map series for Scotland by D. R. Macgregor; a note. By J. S. Bibby, *Scott, Geogr. Mag.*, **94**, 143-144, 1978.
6. Suggested amendments to the World Soil Classification to accommodate Scottish mountain and aeolian soils. By E. L. Birse. To be published in *J. Soil Sci.*
7. Soil research and land use capability interpretative maps. By J. S. Bibby. To appear in *Proc. Roy. Scot. Geog. Soc. Symposium*—Land Assessment in Scotland.
8. Application of land use capability survey in the Western Highlands. By J. S. Bibby. To appear in *Proc. Welsh Soils Discussion Group.*
9. The soils of Sutherland. By D. W. Futty. To appear in *The Sutherland Book.*
10. Three soil profiles from Elephant Island. By R. M. G. O'Brien (Grampian Region, Elgin Office), J. C. C. Romans and L. Robertson, *Br. Antarct. Surv. Bull.*, **47**, 1-12, 1979.
11. Drainage of soils of low permeability: the Slamannan project. By D. Howat, C. M. McCombie, A. J. McGregor (West of Scotland Agricultural College) and B. M. Shipley, *Research and Development Publication No. 8*, The West of Scotland Agricultural College, 1978.

10. TECHNICAL SERVICES

A. W. STUART

The past year has again been a very busy one for the three sub-sections.

A summary of the work undertaken by the individual sections is given in the following paragraphs.

INSTRUMENTATION

A few examples of the wide variety of tasks undertaken by the section are mentioned below.

Spectrochemistry. A SO_2 gas sample cell for use with the laser remote sensing project has now been completed and a beam splitter mounting platform and associated optical mounts comprising: beam steerer, beam enlarger, 45° drop-in mirror, rotating mirror mount, reference channel mount and a gimbal mounted rotating mirror mount, has been constructed. A new RF plasma torch has also been constructed using boron nitride and a P.T.F.E./ceramic sintered material (Fluorsint).

Soil Fertility. A manually operated leaf-press to extract sap from leaf samples has been fabricated and a water-cooled copper heat-sink for use with the " Digestor 40 " system to enable two sample cycles to be carried out per day.

Peat and Forest Soils. A special aircraft fairing has been devised and a set of quick change twin camera mounts for the aerial survey project. A large quantity of components has been produced to permit sampling of field work projects.

Microbiology. A number of gas-tight containers have been constructed for use as greenhouse incubation pots.

Under construction are a novel medium-scale gel chromatographic unit, a copper radio frequency cavity for use as an atmospheric pressure gas chromatograph detector, a nebulizer chamber for use with the new RF plasma torch and, lastly, a syringe injection system for the Calvet Micro-calorimeter.

ELECTRONICS

During the past year there has been a further increase in the demand for routine maintenance and servicing, mostly on equipment which has been in use for some time, but owing to the falling standards of quality control in industry, requests for service to relatively new equipment have become more frequent. This emphasis on maintenance, together with staff changes, has inhibited the intended development of new instruments.

A range of Eurocard-sized microprocessor boards has been designed, which will allow small data handling systems to be constructed simply and economically. The modifications to the Printed Circuit Board Scribing machine, necessary to produce the new boards, are very nearly complete.

Facilities for microprocessor program writing are being continuously improved, but are still rather limited. It is hoped that significantly more progress will be made during the next year.

PHOTOGRAPHY

The routine service to all nine departments continues in the production of transparencies (colour, diazo, black and white) for projection, line work and half tone prints for publication, apparatus and specimen photography and field work.

The acquisition of a new DeVere 504 free standing enlarger with Dichromat colour head, to be used in conjunction with a Wilkinson Colour Processor (a rotary discard machine) will greatly facilitate the production of colour prints from colour negatives and transparencies.

The 504 enlarger has the dual facility of a 5″ x 4″ copy-back and lights, enabling material up to 30″ x 40″ to be copied. Heat seal laminating of photographs and labels, making the latter virtually waterproof for use in field work, can now be undertaken on the new ADEMCO hard-bed mounting press.

Finally, the aerial survey programme for the Peat and Forest Soils Department has taken a further step forward towards the automation of the cameras used for vertical stereo photography, by the introduction of motor drives and automatic aperture exposure control units.

11. LIBRARY

A. H. W. DICKIE

The Library was very busy throughout the year in spite of the inconveniences and limitations caused by reshelving the Annexe. The wooden fixed shelving has been replaced by "Compactus" machine movable shelving, giving an increase in storage space of at least 55%.

251 books were added to stock, and 2 new journals. No journals have had to be cancelled so far in spite of greatly rising costs.

The Inter-Library Loan system was again heavily used, and 731 items were borrowed, including 407 from the British Library Lending Division. 137 items were lent out to other libraries in response to 244 requests. Although the Library is primarily for the use of members of staff, we lend to both individuals and institutions, either directly or through the inter-lending system.

Lists of Available Publications can be obtained from the Librarian. In response to the last list, 2609 reprints were distributed all over the world.

The two Current Awareness Bulletins have continued to be produced—the Periodicals Bulletin weekly, but the Book Bulletin less frequently, due to staff shortages.

As the costs of printing it have risen so steeply, only 20 copies of the Collected Papers, Vol. XII, 1976-78, have been ordered for limited circulation.

APPENDIX

FOURTH

T. B. MACAULAY LECTURE

23rd NOVEMBER, 1979

TREE TOPS HOTEL, ABERDEEN

by

DR G. W. COOKE

Chairman:

Professor T. C. Phemister, MSc, PhD, DSc, FRSE

FOURTH T. B. MACAULAY LECTURE

Aberdeen, 23rd November, 1979

WHITHER SOIL RESEARCH?

G. W. COOKE

Agricultural Research Council, London

I greatly appreciate the honour of being invited to give this, the Fourth T. B. Macaulay Lecture. This Institute, which Macaulay established, is unique in Britain. The founder realised clearly that soil is the basis from which all plant and animal life springs and that research to understand and manage soil better cannot fail to benefit the whole of mankind. His faith has been justified by the achievements of the Institute soon to celebrate its Golden Jubilee; he would have been proud to see it today. The Macaulay Institute has, in the last half century, secured recognition as one of the World's leading agricultural research establishments. The achievements of its staff have an honoured place in agricultural science; the application of the work which has been done to help practical agriculture has greatly benefited farmers in Britain and many other countries.

I have spoken of T. B. Macaulay whose generous benefaction founded the Institute, but I must also speak of the first Director, William Gammie Ogg. After setting this Institute in the right paths, he left in 1943 to become Director of Rothamsted Experimental Station. He was responsible for the reshaping of Rothamsted at the end of the War and for establishing programmes of work appropriate for the peacetime needs of a greatly changed British agriculture. In his 15 years of directing the Station it was roughly trebled in size. I came to know him well and appreciated his friendship and wise guidance in our work. It is a great sorrow to me that Sir William died in September so that I cannot say in his presence how much the worlds of agricultural and science and farming owe to him. Through his skills in science and negotiation, and his personal qualities, he laid the foundations of this Institute in the unpropitious times of the early thirties when there was a world-wide recession and a general retrenchment in public spending on research.

Soil scientists have the task of continuing the work initiated by Macaulay and Ogg. We must extend soil research, in part along the lines already established here, but also in the new directions that will be chosen to meet the changing needs of agriculture. The path will be difficult, partly because the easy things have been done, partly because the money available may be less than we would wish. However, I am convinced that we will be successful and that our work will aid farmers of this and other countries to produce more food for the World's growing population. I propose today to talk about the ways in which we may proceed to extend our subject.

Justifying Soil Research

Because the whole of agricultural production depends on plants which grow in soil, we might expect that there should be no need to justify soil research. Nevertheless it is necessary to explain to other scientists, to administrators and to the public (whose taxes pay us) that agriculture in developed countries is a science-based industry. The application of research is responsible for there being large supplies of cheap and high quality food available to all who can pay for it. But it is now fashionable to criticise science in the press, and on radio and television, and we have to respond to the challenge by stating clearly how our past achievements have contributed to agricultural productivity and the importance of our plans for the future.

We cannot pursue personal research aims in isolation from reality. This was pointed out in an article in Endeavour (1979) which said, " The scale and complexity of research is such that only very large public subventions can sustain it, and the size of these, and their allocation will be determined as much by what is politically expedient as by what is economically feasible and socially desirable. Support for science is dictated not on the basis of its intrinsic worth but by what governments, and the taxpayers who keep them in office, believe it to be worth. Science policy is shaped by the same forces as those that dictate national policies, and national policies profoundly affect the lives of individuals, whether they be scientists or otherwise." Similarly from the USA, Sawhill (1979) writes " . . . there is the feeling that scientific research is insatiable in its appetite for the taxpayers' money, and that this money is increasingly swallowed up with little to show for it . . . The scientific community as well as teachers and educators must do a better job of conveying to the public the importance of basic research . . . People must be told the limits as well as the possibilities of science and, most important, its changing and vastly enlarged role in our national and global destiny."

These are important thoughts at a time when public support for our work tends to decrease rather than to increase. They do emphasise that we must not be complacent about our worth to the community and that we must not be shy in pointing out our past contributions to knowledge of the soil which have increased food supplies. Even more important is the need to plan our future work carefully against the background of agriculture's immediate needs, and likely future development. The plans we make must be so well based that they can be convincingly explained to administrators and the public to substantiate our claims for a share of available resources.

We have some handicaps. One that I believe to be important is that soil science is an old science with its beginnings in the early part of the last century. Our recent work has lacked the development of powerful new concepts such as those which, in other sciences such as radiophysics, or molecular biology, have led to spectacular advances. I fear that we are following well-worn paths in our investigations and lack of vision to explore new areas of knowledge. There is also the fact that soil is an everyday object, and so surrounded by traditional lore, that our customers, farmers and gardeners, consider they are expert in its management. We can too easily accept traditional wisdom, for example on cultivations, and fail to apply our scientific abilities to topics which may be at the very heart of crop growth in soil. More than one commentator has speculated on whether our predecessors were too successful in exploiting early knowledge of plant nutrition through fertilizers. Maybe we should have followed up more vigorously the concepts on cultivation, nutrition and irrigation set out by writers of the last century, notably Davy and Liebig. Have we been slow to define and measure the properties of soil that are responsible for its fertility? Has soil research lost its way in this century?

These problems should be a challenge to us to examine the purpose of soil research so that we can establish objectives that *are* vitally important to the future of agriculture, and which can be *seen* to be so. We must develop concepts that silence our critics and which can catch the public imagination as clearly as those of other scientists who work in new subjects.

Justification by achievement and application

Achievement

There have been many assessments of the progress of soil research and its contributions to agricultural productivity. No doubt the approaching Golden Jubilee of the Macaulay Institute will provide an opportunity for a full account of the progress that has been made so I shall not attempt here to detail our achievements. I should, however, mention a thorough review of the history of soil research prepared by the Soil Science Society of America (1977); I shall refer to several of the individual papers later.

Application

Agricultural research cannot be of value until it is applied to practical production. Application is most easy and quick when it involves only one concept. Substituting the seed of a better variety of crop for the old seed is the best example. Applying fertilizer, or a pesticide, where none was used before are simple concepts too, but may be more costly. When several new concepts are simultaneously introduced application becomes much more difficult and the failures that have occurred have attracted criticism. For example the Weekly Guardian recently used the headline, " Grey future for the Green Revolution," over a discussion of world food production problems. The author stated that the development strategies pursued in the Third World since 1960 have been a failure. " The determination to find ways of achieving a great mutual rapport between man and soil was soon forgotten in favour of increased productivity and its concomitant mechanisation . . . international organisations opted for an increase in yields rather than land under cultivation." The article does admit that the " Green Revolution " boosted yields " quite remarkably," but goes on to criticise it for the inputs that were needed from outside the system — " seeds, fertilizers, pesticides, machinery, heavy plant, dams and canals." Continuing —" the main obstacle preventing a new strategy for rural development is still an unshakeable faith in technological progress. This results in misguided attempts to get men and women . . . to adapt to development, whereas it is development that should be tailored to suit people from a rural background." I believe that we *must* have faith in technological progress, because this is the only way to achieve a better standard of living by securing more output per unit effort. But we must also be aware of the ultimate need to fit development into local conditions of soil, climate and markets; the developments proposed must fit the financial and intellectual abilities of the farmers who will put them into practice.

I have raised these questions because it is now fashionable to discuss the application of research in terms of " socio-economic " problems.

In truth the problems are not new, only the description that has been coined for them. The major nutrients needed by crops were well-known a century ago, but the application of this knowledge was for long prevented in most countries by the social and economic conditions that made farming an unprofitable business. In the period from 1874 to 1939 the nitrogen used as fertilizer in Britain only doubled. The need for home-produced food in the War, followed by the 1947 Agricultural Acts, gave stability and relative prosperity to farming that allowed earlier research to be fully applied. In the last 40 years the N-fertilizer used has increased nearly 20 times. Our research on such a complex object as soil may often have to wait for application until other agricultural developments, economic need, and education of farmers, make it possible.

This discussion is relevant to the founding of this Institute. T. B. Macaulay was determined to help the agriculture of the Island of Lewis, the land of his ancestors. Ogg (1933) states that the demonstration farm on Lewis was established in 1929 " to study and demonstrate the best methods of reclaiming and farming peat land, to explore the possibilities of improving the great areas of common pasture and to lend peat cultivation machinery and give advice to crofters wishing to extend their holdings by reclaiming moorland ". Improvement came quickly " in less than three years a very desolate tract of deep and wet peat land has been converted into a farm . . . (with) excellent pastures on which cows have grazed for the past two summers ". Greig (1938) described the benefits of the extension of the work on Lewis. " Prior to 1929 Lewis imported milk from the mainland and eggs from Ireland; now there is no import of milk and eggs are exported. This change is due to the demonstration of the possibilities of dairying in the Island and to the schemes for poultry improvement initiated by Mr Macaulay." Greig described the way in which enterprising crofters had imitated the methods, but mentioned how further development was impeded by land tenure. " If the system of land tenure were changed so that he who sowed would also reap, there is no reason why the greater part of the Island should remain worthless bog."

The improvement on Lewis was based on the application of existing knowledge of peat land management and crop nutrition. Greig (1938) emphasises the vision of Mr Macaulay that led him to extend the work on Lewis by founding this Institute. He saw the need for more research on soils, and for special attention to the peat and moorland so widespread in

Scotland. I find no statement of the founder of the specific ways in which research should proceed; he clearly had faith in soil scientists and knew that research would widen options, and make further technological progress possible. We trust that those who provide facilities for our work will, similarly, have faith in its future. It is up to us to define problems correctly, and formulate such convincing objectives for research workers that leave little option but for them to agree that soil research must continue to be supported; they will also help us to resist challenges such as that research to aid productivity has gone too far and that we should now turn to work more on environmental questions and on conservation.

WHAT SORT OF SOIL RESEARCH

What is soil science?

Is " soil science " a science? Ogg (1933) had no doubts — " it is now recognised that the study of soils constitutes a branch of pure science . . . the name Pedology has been applied to it." Yet a former distinguished Director, A. B. Stewart (in 1965) repeated Williamson's (1958) question " is there such a subject as Soil Science, or is there merely a hotch-potch of sciences applied to the study of soils?" Stewart replied " while we may in one sense have created in soil science a new discipline in its own right, we are still dependent on the contributions to be made by many different scientific disciplines ". He lists geology, chemistry, physics, botany, and microbiology, and concludes " the soil scientist thus remains a necessarily complex entity, aiming at unification within diversity ". I shall return to the need we still have to amalgamate different disciplines in common effort.

Pure or applied research?

One main difficulty I have had of pursuing my theme " whither soil research?" is that our subject comprises so much. It moves from the essential applied work, such as developing methods for assessing the nutrient content of soils, or soil suitability for particular drainage or cultivation techniques, to fundamental studies on clay minerals, soil organic matter or the microbial life in the soil. I find great difficulty in separating the many facets of soil research into two categories of " applied " and " basic ". Yet in supporting our work, some may wish to see such a distinction. Baker (1979) has recently discussed Polanyi's ideas about the control of research; the latter had written " you cannot serve two masters: you must choose between dedication to the advancement of a system of knowledge, which requires freedom, or the pursuit of applied science which involves subordination . . . We cannot foresee the technical outcome of scientific discoveries. From this we can derive a fundamental positive principle, namely that pure science can only be pursued for its own sake. It also follows that applied science can *not* be pursued for its own sake."

I am not able to see such black and white distinctions for soil research. Parts of our work, say on the control of soil fertility by fertilizing and draining, on soil cultivations, and erosion control clearly has practical aims; it need not be done unless there are problems in practice. Other parts such as furthering our knowledge of the chemical, physical and biological resources of our soil, and the nature and behaviour of its organic and inorganic components, will not be for immediate application. But without these latter components we shall not advance our understanding of soil on which our practical work to adjust its productivity depends. I prefer to see soil research as a whole subject, making full use of the peripheral subjects that can be well defined in such disciplinary terms as soil chemistry, clay mineralogy, soil physics, but having as its core a team who have integrated their separate disciplines in a common aim. I believe their work to be basic research on soil fertility.

Heslop-Harrison (1977) discussed the organisation of research in the light of the post-Rothschild reorganisation of financing. He said that the only valid objective of agricultural research is to show how it is possible to improve outputs in quantity and quality while minimising costs in men, materials, energy and environmental damage. While it was vital to have the competence to meet demands on productive capacity this implied continued search after fundamental scientific knowledge and the continuous assessment of the technologies that might be based on it. Relevance of research was not to be judged wholly as the solving of immediate problems —essential though this may be to the day-to-day well-being of the industry. " Benefits are likely to arise over decades rather than accounting years."

Evaluation of soil research

Finally we must consider how the success of our research should be evaluated, a problem recently discussed by Gibson (1979) in the context of " academic " research in USA. He says that congressmen and administrators are responsible for seeing that government funds for R and D are spent effectively and without misuse. As they cannot judge the value of scientific research, they have tended to emphasise what they can understand — monetary accountability.

Performance measurement, even by experts, is difficult and controversial, and these difficulties have led to " effort reporting " (i.e. amounts of time and money involved). The instruments currently used for measuring the effectiveness of research are (i) effort planning, (ii) indirect performance measurement such as the citation index, and (iii) direct performance evaluation. Effort reporting is " fundamentally flawed as an instrument for measuring either the quality or the quantity of research. Only performance should count in scientific research ".

Direct evaluation of the quality of research " may raise the spectre of a corps of federal bureaucrats who evaluate research results and control funding ". Gibson rejects this possibility saying that *peer evaluation* is a practical and effective basis. It is not only fair, and in the best tradition of science, but is has ancillary benefits such as creating closer contacts between senior and junior scientists, and a spirit of responsibility in individual workers. He states that (for USA) " the peer review process would permit disassembly of the costly government bureaucracy that deals with effort reporting and a reduction in the indirect cost now added by universities to contracts ".

We are able to accept that our work for direct support of the agricultural industry may be valued by practical men and extension workers. Tests of a new variety of crop, a new fertilizer, or a new pesticide are unambiguous and should show farmers the worth of the new option. But only those distinguished and independent scientists familiar with agriculture and with the research that is the background of these practical advances can assess impartially either the value of results from basic work or the direction that it is taking. No other system of evaluation could be acceptable to me.

ADVICE ON OUR FUTURE RESEARCH

In times past scientists were themselves expected to be so familiar with their subject, and with possible applications, that they could plan the future of their work. Since 1972, as Sir William Henderson (1977) explained to you, those responsible for funding research in agriculture and food—the Agricultural Research Council, the Ministry of Agriculture, Fisheries and Food, and the Department of Agriculture and Fisheries for Scotland — have depended on advice from the Joint Consultative Organisation (JCO) for Research and Development in Agriculture and Food. Our work was discussed by the Soil Science Committee, responsible to the Arable Crops and Forage Board. The first published report of the Board (JCO 1975) found two topics in our field that merited the highest priority:

(i) *Nitrogen nutrition of crops:* work should include more effective use of N-fertilizers, physiological factors affecting uptake, transport and storage of N, mechanism of protein synthesis within crops, production, transformation, movement and losses of nitrogen in soil.

(ii) *Maximum crop yields.* The best yields of arable crops fall short of their theoretical maxima, national average yields per acre are well below their practical potential. Interdisciplinary research on soil/site interaction was advised to raise both average national yields and maximum potential yields.

An important point is that these two topics were among the ten priority subjects established by the JCO as a whole.

The Soil Science Committee (JCO 1975) set five main priorities: maximum yield studies; nitrogen nutrition of crops; soil survey (the production of maps to proceed speedily and their usefulness to be ensured); soil fauna (in relation to physical conditions and the decomposition of organic materials); reduced cultivation and direct drilling techniques.

The next Reports (JCO 1977) record that ARC had set up a Priorities Working Party to establish a few high priorities across the whole research area. Two of the three priorities accepted by 1977 are in our field: soil root relationships; causes of variability in crop yields; (the third was bioenergetics and photosynthesis). The 1977 Report of the Arable Crops and Forages Board again stressed the importance of further work on nitrogen nutrition of crops and on maximum crop yields; these were two of the Board's seven priorities. In that year the Soil Science Committee made 23 recommendations, all of which deserve careful study. I list only those given highest priority:

(i) experiments aimed at maximising crop yields and elucidating soil factors which limit yield;

(ii) efficient use of soil N, and N-fertilizers;

(iii) efficient use of biologically fixed N;

(iv) the mapping programme of the Soil Survey to proceed as rapidly as possible;

(v) specifying soil conditions for good seedling emergence;

(vi) factors limiting the transfer of water from soil to crop;

(vii) the need for the Soil Survey of England and Wales to determine trace elements (total and available) in principal soil series.

The Plant Science Committee of JCO (1977) also made recommendations relating to soil research. They gave the highest priority to 32 topics; the following were among them.

Nitrogen uptake mechanisms by roots should be the subject of a basic programme.

Plant/soil/water relations needed better understanding, particularly relationships between water stress and plant growth. More knowledge was needed about (i) interactions between rooting patterns, roots and soil properties and plant water stress; (ii) transfer of water across the soil/root interface and through the roots; (iii) the effect of water stress on biochemical and physiological aspects of plant development, including adaptation and recovery from stress. Improved understanding of soil physical properties in seedbeds affecting water relations was needed. Better understanding of the patterns of water movement and of percolation processes, particularly in well-structured soils, was essential. Basic work on the physics of water flow should be maintained.

Phosphorus nutrition merited intensive work to investigate the interactions between soil and plant factors. Work on the effect of vesicular arbuscular mycorrhizas on phosphate uptake should be supported; work on other rhizosphere organisms and root exudates was interesting.

Trace elements needed more work, especially the effects of shortages and excesses.

Our future programme

I see our future work as classified under four headings:

(i) Support work for agriculture.

(ii) The inventory of our soil resources.

(iii) Basic research on soil components and properties.

(iv) Integrated research on the soil as a medium for crop growth.

The purposes of research on the first three subjects and the kinds of work to be done are clear; most of the topics have been discussed by JCO. I will spend little time on these subjects, giving no more than an incomplete outline of the kinds of work needed.

Support for agriculture

Our agriculture now depends on inputs that are the result of research in science and engineering. We have to provide the background work to make these inputs more efficient, to develop new options for farmers to consider, and to safeguard the environment. Such work is appropriately considered for commissioning under the customer/contractor arrangements initiated by the Government's 1972 White Paper following Lord Rothschild's 1971 Report. I list below some topics that must be pursued to help agriculture to become more efficient in its use of resources without damage to the environment.

(i) Assessment of soil fertility by chemical methods and biological experimentation.

(ii) Comparisons of forms of fertilizers, and methods of application; work to make N, P, K, Mg, lime and trace elements applied as fertilizers more efficient.

(iii) Reactions of agricultural chemicals (pesticides) with soil.

(iv) Effects of soil properties, farming systems and fertilizers on crop composition and quality.

(v) Effects of farming systems on soil, water and air components of the environment, aiding the control of pollution and soil erosion.

(vi) Physical work on soils to aid drainage, irrigation and efficient water use, and to support the development of cultivations and soil management.

The pace of this work will be set by the progress made in practical agriculture; the problems, so far as we do not discern them ourselves, will be put to us by agronomists, farmers and public opinion; we expect the priorities to be determined by JCO which, in its newly defined pattern, will have definite tasks given by its sponsors.

Inventory of resources

The work of the Soil Survey to describe and classify our soils is clearly of the highest importance. Equally important is the work of chemists, mineralogists and others who measure concentrations and forms of elements, and the nature of minerals in the soils described as well as the physical properties that are important in the field. This information is often the background for those concerned with both crop and livestock production. It will also become more important as agricuture intensifies; doubling of production per hectare from plants or animals doubles their nutritional needs and increases the likelihood of soil reserves becoming inadequate. We should not underestimate the task of dealing with the masses of information that arise from field and laboratory work, particularly aided by the methods of instrumental analysis in which the Macaulay Institute has played a distinguished part which is recognised the world over. Modern ways of storing and retrieving information have a vital role here to aid the work of our customers — other agricultural scientists.

I must praise the excellent work of the Soil Survey for Scotland established as a Department of the Institute by Sir William Ogg. I need not discuss modern issues because Professor Russell spoke here two years ago on " Soil Survey Methodology and Agriculture ".

Basic research

I have already quoted from Heslop-Harrison's justification for basic research on our working materials — plants and soil. It is often difficult to point to the immediate short-term value of some recent advance in our knowledge of soil components. But it is easy to show how gains in understanding of soil processes have come from work on clay minerals, organic matter, forms of nutrients and how they have aided other scientists and improved advice given to farmers. Two examples are the ways in which new knowledge of clay minerals has elucidated the processes of fixation and release of potassium and the value of knowledge of the organic fraction in work on soil structure and management and on crop nutrition.

Advances in basic knowledge of soils have been so comprehensively described in successive editions of Russell's (e.g. 1932, 1973) Soil Conditions and Plant Growth that there is no need to spell out the great advances made in the last 50 years, particularly by the application of modern techniques developed by physicists, chemists and biologists. Such work must go on. I must, however, draw your attention to two fields where extra work will be needed.

Soil microbiology. In Russell's 6th Edition, appearing in 1932 — about the time the Macaulay Institute was formed — one chapter, about one-eighth of the book, describes work on the micro-organic population of the soil and there are further references in the following integrating chapter titled " Biotic conditions in the soil ". It is the living organisms in the soil which distinguish it from a heap of inert mineral and organic materials and I do think we have lost the impetus of early workers in some aspects of soil microbiology and zoology. The importance of microbiology can be gauged from the collection of essays edited by Walker (1975). I think that the extension of such work will be an essential component of the integrated work that is needed to advance soil research. Excellent work is being done in many countries on the microbiology of nitrogen fixation. Important advances have also been made recently in understanding the important role of mycorrhizal associations in crop nutrition. But I think there is too little work at present on wider aspects of microbial activity in soil, particularly on the role of microorganisms in nutrient cycling, their effect on soil structure, and their interactions with plant roots.

Clark (1977) described advances in the USA. He emphasised the importance of microbes in ecosystems; in grassland soil their dry weight is $100g/m^2$, much greater than the weight of vertebrates and invertebrates associated with the system; the dry weight of large mammals is $1\text{-}5g/m^2$, depending on stocking rate, smaller creatures total no more than $4g/m^2$. Clark points out that the P contained in microorganisms under grassland is twice that in the herbage; cumulative uptake of P by microorganisms is 5 times the seasonal plant uptake (because the microbial population turns over so fast). There should be no need to mention the importance of microorganisms in the nitrogen cycle. Clark pointed out the current diversion of microbiological effort to problems of environment and of waste utilisation.

Soil physics. Progress in this subject seems to be inadequate for our current needs. In 1896 (83 years ago) Warington gave a series of lectures which were published (1900) under the title " Physical Properties of Soil ". His chapters dealt with physical constitution of soil; relations of soil to water, and to heat; and movement of salts in soil. He apologised for having to give as examples, the results of work in USA and Europe because so little had been done in Britain saying — "the deficiency of knowledge of our own local soils is nevertheless a very real evil, and must greatly hinder the practical application of general principles ". He went on to stress the great advances made in agricultural chemistry, but said that advice on manuring based on these advances was liable to be useless unless account was taken of physical factors; if farmers found that advice which neglected soil condition led to poor results, they concluded that science was not a safe guide to agriculture.

Keen (1931) used the same title for his book which gave an account of the considerable progress that had been made by physicists in the first third of this century. In particular, progress in studying the architecture of soil — including the complex relationships of pore space and capillary films of water — was made by Haines. Later excellent progress was made in studying soil water (for example by Childs (1969) and his colleagues) and by Schofield and others in applying thermodynamic principles to solutes and their movement in soil. But it does seem that physicists have not attemped to take studies of soil architecture further and in particular they have not applied their expertise to the changes in porosity caused by plant roots and the soil population. This has led Greenland (1977) to write: " In general there is a serious lack of knowledge relating to soil physical conditions and crop production. An appropriate analogy is with plant nutrition about a century ago, when we were just beginning to understand the importance of correcting specific nutrient deficiencies to improve plant growth ".

Gardner (1977) wrote that soil physics began in USA about 100 years ago. Particle size distribution and soil structure were the early major themes, but these were gradually displaced by water relations. Modern needs are for development of more comprehensive mathematical models of plant growth so that the topics in soil physics needing more work can be identified.

Soil research

Examining the kinds of work I have discussed in the three preceding sections against the recommendations of the Soil Science Committee (JCO 1977) I find that over half are for support work for the industry, a quarter are for basic investigations, and 3 of the 23 recommendations are for an inventory of soil resources. I am left with one top-priority recommendation " The wider use of experiments aimed at maximising crop yields and elucidating those soil factors which limit yield ". At first sight this may seem very applied work, justifying my " support " classification. In fact

I consider this recommendation is the pointer to the new kind of soil research that industry requires and which we must develop. The Board, in endorsing its Committee's recommendation, states " The factors and interactions which produce maximum crop yields need further investigation. This work can be expected to produce guidelines for the definition of the conditions necessary for the attainment of maximum profitable yield and an increase in the national average yield per unit area ".

Earlier advice

Fourteen years ago Stewart (1965) drew attention to the need for co-operative studies on the interactions between factors affecting crop growth and particularly on the soil volume from which roots draw nutrients and water, and which is continually varying. At about the same time the then Secretary of ARC, Sir William Slater (1963), wrote in a Foreword to the Macaulay Institute's Report, " Without the knowledge such study (i.e. of soil) can provide we cannot manage our soils to obtain the maxium yields and at the same time preserve or increase their inherent fertility ".

Over thirty years before Slater, Hoagland (1931) stressed the need for investigations to relate soil conditions to plant growth. Co-operative effort was required — not of formal or official type, but resulting " from a common interest in a general objective by men of different specialisation ". He then made this very telling statement — that the object must be so to understand the properties governing plant growth that they can be controlled so that " it becomes possible to do exactly the same thing twice ". Has soil research lost its way in the last 50 years in spite of the good advice we have had?

A world-wide basic problem

The question of why average yields are so far below good farmer yields which, in turn, are below the established potentials is now receiving world-wide interest, though I believe that we were the first to draw attention to it. Table 1 shows that on the world scale average yields are only one-fifth to one-seventh of established potentials. Average yields in developed countries are two or three times larger than those in developing countries. But even the best country average yields reported by FAO (1970-76) are less than half the practical potentials which have been achieved by some farmers. Table 2 illustrates the situation in Britain by stating a few recent average yields, known potentials and authenticated yields achieved by farmers or experimenters. Last year there were reports of wheat yields of 11·3 t/ha obtained by a farmer on a large field (Hope, 1978). This year Rothamsted reports 12 t/ha of wheat grown in an experiment designed to investigate causes of yield variability. Austin (1978) gives the theoretical potential of wheat yields as 11.4-12.9 t/ha.

Why is this very practical problem of failure to achieve yields a very basic problem in soil research? When farmers and advisers are questioned they can often guess why yields were *poor*, but neither they, nor research workers, can detail the special circumstances that lead to *good* yields. Hope's reasons for the large yield of wheat quoted above were " thorough

TABLE I

Average yields (in t ha^{-1} of product) of important crops in regions of the World

	Wheat	Rice	Maize	Potatoes	Peas	Ground Nuts	Soya Beans
Established potential yield	12	14	13	90	—	—	—
Average yields (F.A.O.)							
World	1·7	2·4	2·8	14·4	1·2	0·9	1·4
Africa	1·0	1·8	1·1	8·3	0·7	0·7	0·4
N.C. America	2·0	3·7	4·5	23·0	1·6	2·3	1·9
S. America	1·4	1·8	1·6	8·2	0·8	1·2	1·5
Asia	1·2	2·4	1·9	9·8	0·9	0·9	0·8
Europe	3·0	4·8	3·8	19·3	1·6	1·9	1·2
Oceania	1·3	5·6	3·8	20·8	1·8	1·2	1·5
U.S.S.R.	1·7	3·8	3·3	13·4	1·5	0·8	0·5
Average for economic regions							
All developed	2·2	5·7	5·0	21·7	1·8	2·1	1·9
All developing	1·2	1·9	1·3	8·5	0·7	0·8	1·3
Centrally-planned	1·7	3·1	3·0	13·6	1·2	1·2	0·8
Best average yield in country with large production	5·2*	6·0†	5·7‡	37*	—	—	—

* Netherlands † Japan ‡ U.S.A.

TABLE II

Average Yields of Crops and Proved Potentials U.K., 1978.

	Average yield (U.K.)	Potential yield (proved on farms)
	tonnes per hectare	
Wheat, grain	5·2	11·3
Potatoes, tuber	32	90
Grass, dry matter	?	25

deep cultivations and moisture control ". Farmers I have questioned about the source of their large yields have only been able to reply " everything went well ". Austin considers drought a major cause of yield variability in cereals, but he surveyed experimental results which showed that irrigation increased wheat and barley yields by no more than 17 per cent. If drought is the main factor limiting yield why were average responses to watering so small? It is environment that settles potential yield and, over restricted areas where climate varies little, soil fertility is the only changing component of environment.

I consider that when crop diseases and weeds are eliminated, as they can be, that the factors which affect yield of a healthy weed-free crop are related to the supply of water and nutrients as they are affected by the physical and biological conditions in the soil—in other words " root-soil relationships "—the research topic identified by ARC's Working Party on Priorities. We soil scientists cannot join with agronomists and, by applying all normal known inputs to a particular site, achieve the accepted potential yield of a cereal crop. This is because we do not fully understand the factors controlling soil fertility and therefore we cannot control them. This is a research problem in soils, and it is our problem. We may have to defend such work from the attacks that some practical people make on research directed towards attaining maximum yield by clearly stating that our efforts are not directed towards increasing practical yields irrespective of costs of inputs. We must point out that we strive to understand the relations between roots and soils so well that we can, at will, achieve the yield that a crop is capable of providing in a given climate. Success will bring " spin-off " benefits to farmers by helping them to improve the fertility of their soils and, by making inputs more efficient, lessening costs of production. The cereal harvest in Britain will total 17 m t this year, worth £1700 million. If it could be increased by only 3%, the extra crop would be worth about as much as was available to ARC in 1978/9.

I propose in the second part of this lecture to give my views on how I hope we may progress. Many of the topics I shall discuss are old, but they need to be reopened. This may not always be welcomed; in Sir Bernard Keen's (1931) words " an ancient art, such as agriculture, embraces many traditions and generalisations that do not survive the test of scientific examination, and the iconoclast serves an essential albeit an unpopular function."

We need new concepts to give us a springboard into the future.

Basic Concepts in Crop Production

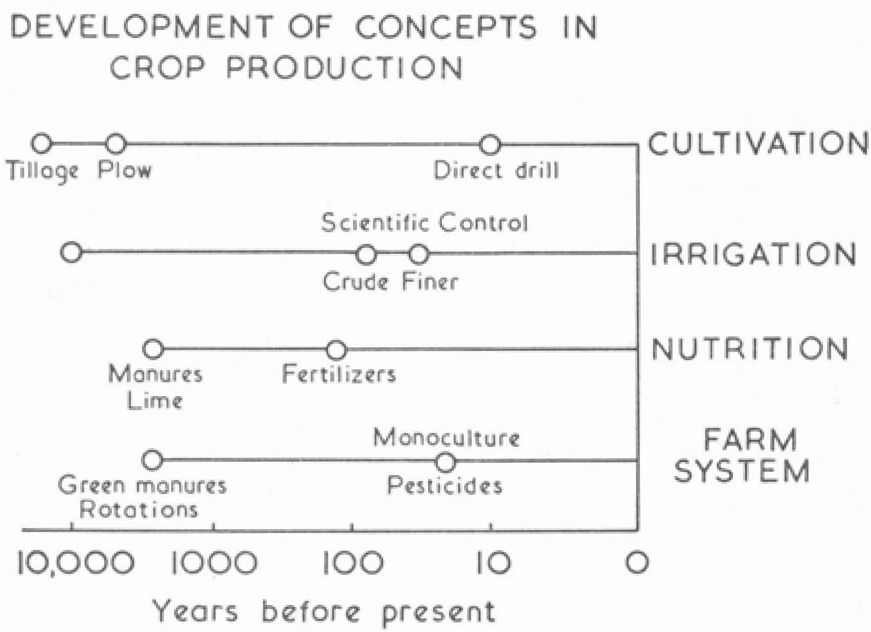
In this section I review development in the concepts which have given man increasing control over relations between the soil and the plants on which he depends.

Early developments

Until the 19th century arable agriculture depended on four ancient innovations: (1) clearing of vegetation and stirring of the soil to receive seeds or plants that provided food; (2) watering of plants in dry conditions, developed into irrigation systems; (3) adding plant and animal wastes, and sometimes calcareous materials, improved crops; (4) rotations of crops which was more productive than growing one crop continuously. All these advanced practices were well established 2000 years and more ago.

Cultivation

Presumably cultivation began when someone had the idea that seeds gathered for food could be planted in areas cleared of vegetation and after stirring the soil by a stick. Crude ploughs were developed in Neolithic times, later mouldboards were added. Keen (1931) has reviewed the later development of implements to till the soil. No new concepts were developed until recently and Scott Russell (1977) has pointed ou that " until the early part of the present century no other aspect of agricultural practice was more guided by tradition, and less by scientific enquiry, than the cultivation of the soil." Proof that the age-old practice of ploughing and cultivating the



soil was not essential to the successful production of arable crops was provided by Keen and Russell (1937) and Russell and Keen (1938). They showed that under many conditions the optimum cultivation was no more than that needed to create a seedbed and destroy weeds; working the soil more was likely to lessen rather than to increase crop growth. This work was ignored by most soil researchers; it was deprecated by many agriculturists who saw it as an attack on the strongly maintained " principles of good husbandry." Meanwhile, in the post-war period our farmers developed their ritual of stirring the soil by buying ever more powerful tractors to plough deeper, and to pull heavier cultivators to pulverise soil finer. However, in this same time, dissident research workers made long-term experiments to show deeper ploughing was often no better than shallow (Russell, 1956), and to confirm that all that was *essential* was surface tilling to control weeds and create adequate tilth for sowing seeds (Moffatt, 1975). Exceptions to these general statements are that ploughing is necessary to remedy the damage caused by heavy machines which create ruts on the surface of soil and damage structure beneath. Increasing unease about the long-term effects of such damage led to the production of the Strutt Report " Modern farming and the Soil " (Ministry of Agriculture, Fisheries and Food (1970)).

However, the traditional wisdom of cultivating had already been challenged in the early 1960s when the bipyridyl herbicides were introduced. These chemicals, and later introductions with similar properties, kill all green plants and leave no active residue in soil. From this time on it was no longer necessary to cultivate to kill weeds; seeds could be sown directly in a slit, or narrow stirred ribbon of soil, in the undisturbed land surface. Farmers were quick to perceive the benefits of " no-till " direct drilling and minimum cultivations systems; they saw these techniques saved tractor fuel and, even more important, time needed for autumn sowing. As machines improved, and experience was gained, direct drilling increased and in 1978 116,300 hectares of autumn-sown crops were established in this way in Britain. Greenland (1977) describes these developments as " the first real step forward in land preparation for crop production in about 3000 years . . . we can now think a lot more positively about what is needed in terms of ensuring that the soil is in the most suitable physical condition for maximum crop production, and if tillage is necessary it is conducted for this purpose."

While farmers saw the financial gain from these new methods, and applied them, research workers have been slow to realise their conceptual importance. Farmers accepted the losses of organic matters and crop residues, and damage to soil structure and the micro populations of the soil, caused by cultivations because they had no alternative. Soil workers also accepted them as inevitable and now they are being very slow to recognise the importance of this new concept for soil fertility studies. It is no longer necessary to accept that physical improvements to soil created by an annual crop will be destroyed at the end of the season by ploughing, or that its residues which could increase the soil organic matter will be decomposed and lost. Neither is it necessary to distinguish between the surface (Ap) horizon and the subsoil horizons; the whole profile must be the concern of the soil researcher.

Irrigation

Watering of crops in arid areas is a very ancient practice which remained empirical for thousands of years. American workers (notably King) attempted a more scientific basis in the last century and this led Viehmeyer and others to recommend systematic methods of watering for arid areas which used water more efficiently and prevented the accumulation of salts.

Further progress in control of the irrigation given to supplement rainfall in countries like ours was achieved as a consequence of the work of Penman and others who examined the capacity of crops for transpiration and developed recommendations that depend on weather data, supplemented by measurements of available water capacities in soils.

Since irrigation may be an input in experimentation to achieve crop yield potential I must repeat a question I have asked previously (Cooke, 1979): " Can irrigation applied to the surface be equated with reserves of water stored in subsoils? " I question this because uptake of water is intimately connected with uptake of nutrients and crops cannot grow well if their moisture supply is in the topsoil and nutrient reserves are in dry subsoil. King (1892) described experiments with weighed barrels of soil which received rain and supplementary watering either on the surface or to the base of the barrel, 40 inches below the surface. Surface watering to keep the weight constant did not maintain growth of maize. King found that water in soil in the lower part of the barrel was depleted so that " the corn was really suffering for water in spite of the fact that the surface foot contained an abundance of it." After wetting of the lower soil the corn improved; saying that he could not explain the result, King wrote " it is very suggestive as to the great importance of the right amount of soil water at all times that, in spite of the deficiency of water for a time in the barrels, the actual yield of dry matter was 19,845 lbs per acre while that of the field surrounding it was only 8190·5 lbs." Such effects appear not to have been thoroughly investigated with modern equipment. Penman (1966) records a sophisticated weighing lysimeter installation at Rothamsted, Dagg *et al* (1969) described parallel equipment in East Africa. No results relevant to the issue I raised appear to have been obtained.

Nutrition

Roman writers of 2000 years ago record that crop and animal wastes added to soil improved growth and that calcareous materials also had good effects on some soils. (We now recognise that wastes return nutrients to soil and that lime-supplying materials neutralise soil acidity.)

The next advance was made in the last century when Lawes, Gilbert, Liebig and others showed that the nutrients needed by plants could be supplied as inorganic chemicals. Production was no longer limited by the supply of nutrients in the farming cycle, or the natural system it replaced; productivity could be raised far above that of the natural climax association. Jack's (1963) appraisal is worth quoting: " the philosophical implications of this tremendous breakthrough of mankind have as yet scarcely penetrated into the realms of soil science . . ." Statistics of fertilizer use suggest that developed agriculture has gone far to exploit the breakthrough, though we cannot pretend that fertilizers are used efficiently even now. But I repeat Jack's point, many soil researchers have not yet built into their thinking the simple fact that growth of field crops need *not* be limited by nutrition; however to be *certain* that they are not limited we need to know much more about movement of nutrient ions in soil and the varied physical and biological processes by which they transfer to plant roots.

Crop rotation

Rotations, used since Roman times, had the historic role of supplying extra nitrogen (when legumes were grown), of diminishing the effects of the soil-borne pests and diseases prevalent when only one crop was grown, and of allowing better opportunities for weed control. The steps forward we have recently made are: (1) We can now avoid the need for extra nitrogen from legumes by using fertilizers; (2) we can control weeds by modern herbicides without cultivation or rotation; (3) we can poison pests that persist in the soil, but little progress has been made with control of the soil fungi that damage crop roots (e.g. take-all of wheat and barley caused by *Gaeumannomyces graminis*) — such soil/plant interface problems of root disease have attracted much research over the last 40 years — with little benefit to practice; they merit a place in joint investigations by multi-disciplinary teams.

Soil Research and the Assessment of Soil Fertility

One of the founders of modern soil science, G. W. Robinson (1932) wrote that soil fertility was " the ability of a given soil to grow satisfactorily some or all of those crops permitted by the regional climate." He struck a very modern note by stressing (1) that economic, social and personal factors intervene in agriculture so that what is grown only partially reflects soil and climate, and (2) the need for soil conservation so that " the fullest utilization of the earth's resources may not be incompatible with the conservation of these resources of permanent agriculture." Most early discussions on soil fertility concentrated on nutrient supply. At about the time this Institute was formed Russell (1932) wrote: " In a fertile soil the net rate of production of nutrients available for the plant completely satisfies its requirements." We must take this as a basic principle; remember that the " net rate of production " must refer to the amount available at the soil root interface, not in the surface soil, or in the fertilizer bag.

Russell (1932) went on to discuss the factors involved in the ability of soil to supply air, water and nutrients at rates sufficient for unchecked growth: Easy root growth depended on pore space and mechanical composition of soil; clays should be calcium saturated. Residues should be incorporated in soil so that microorganisms converted organically-bound nutrients to simple ions. Losses by leaching should be minimal. In humid temperate climates cultivators wishing to improve soil fertility should: (1) Increase water supply by adding colloids; deepen soil by breaking pans and enriching the subsoil; increase air supply by drainage. (2) Build up " compound particles " by proper cultivation and by adding organic matter and calcium carbonate. (3) Ensure that soil pH suits crop and micro-organisms. (4) Add nutrients by fertilizers, green manures and farmyard manure (FYM). Soil " exhaustion " resulted from loss of nutrients or damage to the " compound particles." Russell distinguished between temporary fertility (" condition ") controlled by the farmer and " inherent " fertility that " depends on the unalterable compound particles."

Recent writers have given no better assessments of soil fertility that we accept today. Because they go no way to providing a basis for investigating the soil properties responsible for yield, I question what progress we have made in the last half century in understanding soil fertility. In a similar vein Viets (1977) recently reviewed the history of soil fertility research and concluded that most soil research and soil science was in a quiescent stage, although there was vigorous work on isolated but topical problems such as nitrogen supply and possible damage to the environment. Future advances would depend on understanding interactions between manageable production factors and the integration of these factors into whole management systems. Research would need intensive regular measurements of critical parameters to monitor changes affecting crop development. He concluded: "We cannot solve current and future problems in soil fertility and soil productivity by a nostaligic return to some or all of the practices we used in former times. If the field of soil fertility, and progress in it, goes to sleep, we as scientists will not be meeting our obligations." While I regret that Viets did not feel able to define those "critical parameters," I cannot but agree with him; even though we may not have gone to sleep, I think we are in danger of becoming soporific.

Fertility of the whole soil

Other approaches to soil fertility problems have attempted to progress by considering the whole soil. This attitude is often taken by those associated with the organic farming movement but their statements are usually in qualitative terms. Balfour (1973) stresses the need to break away from fragmentary techniques and so move to observing whole systems of soil to plant to animal. She defines soil fertility as "the capacity of soil to receive, store and transmit energy." G. V. Jacks (1963), developed the idea that the natural fertility of a soil is a bio-physical rather than a physico-chemical phenomenon. He defined fertility as the capacity to support the climax population of plants and animals above ground and the associated flora and fauna below ground. He wrote: "It concerns the transformation of energy in living organisms; essentially the transformation in plants of heat and light into chemical energy which is returned to the soil to provide energy for the edaphon (those organisms which make their homes mainly or entirely within the soil) to live and work to construct a habitat." A climax association of plants and animals have made the best possible living conditions for themselves, and the productivity of the soil is then the highest possible under the prevailing conditions."

Avery (1962) considered fertility from a pedological point of view. "The productive capacity of a soil under given climatic conditions is largely governed by its suitability as a rooting medium, and by the ability of the horizons penetrated by roots to store water and nutrients in forms accessible to plants . . . Wherever farming is intensive, we are concerned not so much with the harvest to be expected from a soil in its virgin condition, but about the extent to which the more permanent soil characteristics (as integrated in particular soil types) are effective in limiting responses to particular management practices or ameliorative measures." Avery stresses that the physical arrangement of the soil governs its suitability as a "home" for plant roots.

The present position

The natural structure of soil, built up by the climax population, and its associated nutrient cycles, cannot be maintained in traditional arable cultivation which destroys structure by tillage and removes nutrients in crops. We may reasonably assert that we have a scientific basis, though it is rough, for controlling the nutrient supply to our crops by fertilizing, growing legumes and recycling wastes. The processes are inefficient, particularly with N, but no doubt we will do better. But this is as far as we have gone. Our failure to secure effective control of the fertility of soils used for crop production, so that we can grow predicted yields, is because we do not properly understand the physical and biological climax conditions even in natural soils and we are even more ignorant both of the complete needs of our cultivated crops and of the effects on soil. We need to establish the condition and properties of soil for the maximum yield of crop on a given site—that is the *cultivated* climax association.

I am convinced that we must regard the soil as a whole and must study all its living and non-living components, we must also make progress with biophysical aspects of the soil/root interface if we are to understand soil as a root habitat. Greenland (1977) wrote that it is a reflection on the values of the first half of this century that while our knowledge of physics and technology developed to the stage where we are now able to fly to the moon, we have failed to develop the skills that allow us to measure the structure of the soil. He stressed the need to concentrate on soil porosity rather than on solid structural units, stating that we must, in future, become able to establish " soil conditions which enable plants to grow to the limits imposed by photosynthetic rates."

SOIL ARCHITECTURE

The points discussed in the last section led me to ponder on the relation of living things to their environment. Through millions of years of evolution plants and animals have adapted to local conditions, partly by changes in their own organisation, partly by the changes they have caused in their environment. If they couldn't make these changes, they didn't survive. Man has no better physical ability for surviving away from his natural habitat than other animals. The difference is that we have a wealth of information collected through history, and an ability to use this knowledge as a basis for future action. Above all we have the ability to develop co-ordinated activity by groups of people to change the environment—for good or ill. This ability for concerted action has given us the cities in which most of us live, the agricultural landscape which has replaced a natural landscape, and the scientific research which has changed our lives so much this century. We now have the ability to travel around, to store information, to communicate, and to create specialised societies whose sections depend on one another for transport of food and other needs. When we get things wrong we create eroded or war-damaged landscapes. But this is *all* above-ground activity; we have done little to adapt the deeper layers of the soil to our needs — in fact drainage of some wet lands is the only agricultural example I have.

Philip Morrison's (1979) Jacob Bronowski Memorial Lecture, where he contrasts the abilities of man and of termites to create structures, appears relevant. He told of the termites which dominate some parts of the Australian and African landscape. They build cities of soil which house perhaps a million insects; the building and maintenance of their mounds is governed by inherited rules of social behaviour. (Sands (1979) has described termite activities in more detail.) The termites are farmers; their crops are fungi " sown, tended, cropped, reaped, propagated and resown by the termites . . . In the cross section of the nest of *Macrotermes* one sees a deep central region of many warm damp chambers, where the fungus garden is kept and tended by the devoted horticulturists." Humidity, temperature and air flow are carefully controlled. The whole structure is purely functional, there is no blueprint; the ability to create a suitable structure is the result of an inherited behaviour pattern developed over millions of years. The clue is the ability to build an arch of the right size in the right place. By physics and engineering man has developed the same ability to build arches, *but above* the soil surface!

Our ability to build soil structure is in sharp contrast to that of the termites. Bridges (1978) has described the history of man's effect on soil. In 18,000 years of growing crops we have done no more than to destroy natural vegetation and to stir up the soil to plant the seeds we have domesticated. We have acquired little understanding that helps us to improve soil architecture so that it suits the roots of our plants better. We are certainly far behind the termites in our ability to manage soil. You may say the termites are simply the equivalent of glasshouse gardeners; I would remind you that traditional lore still dominates the physical preparation of glasshouse soils; many growers have escaped from soil in favour of more homogenous and malleable materials—peat or straw, some are following the plant physiologists in using the solution culture they call " nutrient film technique." Some 25 years ago we thought that the newly-introduced chemical soil conditioners would have profound applications in soil structure studies. But it became clear that conditioners can only stabilise a structure that has been formed. They cannot tell us that this is the most desirable structure and, of course, they cannot make crumbs out of clods.

The important difference between man and termites is that the latter became able to modify their soil environment by natural selection over millions of years; but we cannot wait. By the collective reasoning and action of collaborative research we must learn to modify soil environments to benefit the roots of our crops in our lifetime. Individual action will be ineffective, the groups of scientists must be of sufficient size and complexity of disciplines that they can " take off " to permanent achievement in gaining the understanding that will lead to better soil management.

How far can the rigid disciplines of physics help us in assessing the needs of the roots of our plants and are they capable of dealing (by measurement) with the ever-changing physical conditions in the soil's porosity?;—the solid particles *can* be assessed, but they don't matter!, all the *life* of the soil takes place in its pores. As I discussed earlier, it does seem that the approach of pure physics had taken the subject as far as it could by the end of the 1920s.

More helpful to our present need is work in micromorphology—pioneered by Kubiena (1964) since the 1930s. The ability to identify the different components of the soil's fabric and the extent and nature of the porosity is vital to understanding root growth, aeration, water relations, solute uptake and the soil as a habitat for smaller living organisms. Bullock and his colleagues (1976) have taken the subject much further in this country. Particularly important is the measurement of soil architecture and porosity, made possible by image analysing computer (Murphy et al, 1977). However, these measurements are for " dead " soil and for the static situation at the time of sampling. We must proceed to the far more difficult task of dynamic measurements in deeper horizons of the " living " soil, and its co-operative organisation. Such highly structured systems need much information from several disciplines to describe them sufficiently for our purposes. Civil engineers *have* made progress with those parts of soil physics dealing with soil mechanics; but their objectives are the reverse of our—they need a solid and impervious base for their *above-ground* structures!

Progress in Research on Soil-Root Relationships

The termites achieve correct humidity, temperature and air flow for their larvae and their fungal gardens. Some older texts might have us believe we already know the corresponding needs for our crop roots, but much of what we have read is traditional wisdom rewritten in scientific language, but without quantitative specifications for whole soil. However, recent books show that we *are* making progress in studying the soil-root system. Scott Russell (1977) gave a wide ranging account of interactions between root systems and the soil. He emphasised the multidisciplinary attacks that are needed and, finally, he discussed the functions of tillage and the possibilities of new systems of soil management. Nye and Tinker (1977) described progress in studies of the components of the root-soil system. They concentrated on solute movement from soil to root and discussed the construction of models that integrate information for plants growing in field soil. Several chapters of Walker's (1975) " Soil Microbiology " are relevant to my theme; the book is largely a review of some of the work done at Rothamsted in the last 70 years and it does not attempt to integrate facets of microbiological studies with studies in other disciplines. The present state of knowledge on the modification of soil structure was well reviewed in a 1976 Symposium in Australia (Emerson, Bond and Dexter, 1978). Perhaps it is characteristic of the present state of this subject that the book has neither introduction nor conclusions.

A few topics are discussed in the following sections.

Nutrition

Nye and Tinker summarised the present situation by saying that our knowledge of some nutrients (e.g. N and K) behaving in a relatively simple way over a short time is at least adequate. For phosphate, and probably for most micronutrients, they say the processes involved are so complex and so open to modification by the plant, that present knowledge is not satisfactory. The plant parameters related to uptake are not properly known since the relationships assumed are empirical and may be over simplified. This work on solute movement to roots is a vital part of our story, but it is *only* a *part*.

Roots

Roots modify soil architecture by the local pressures they create in growing and by the channels they leave when they die and decompose. They also modify local soil conditions by the exudates they produce (which may vary between 2% and 20% of total plant dry weight!); these and the mucilages surrounding root tips provide food for microorganisms and greatly encourage their growth and function. Root exudates also modify inorganic constituents of soil and they may inhibit the growth of other plants as Pickering (1917) suggested long ago. There are many puzzles. One is the reason for the stimulation of root growth by high local concentrations of nutrients; although observed years ago (e.g. Cooke (1954)) the physiological and biochemical mechanisms involved have never been unravelled, the processes are clearly of great importance to plants in their efforts to exploit and modify the soil environment. The mechanical relationships between root and soil involved in growth, have never been put on a firm basis. A final point put to me by my colleague, W. Wise, is the question of how much photosynthate is used in constructing a root system? A small root system confined to the upper soil, but supplied with nutrients and water, might leave the maximum amount of photosynthate to build the yield we wish to harvest!

Microorganisms

Bacteria in soil greatly affect the production of nutrients in soil and probably affect uptake. Work on microorganisms has lately been dominated by studies of mycorrhizal fungi. Fifty years ago it was well established that ectotrophic mycorrhiza aided nutrient uptake, particularly of forest trees (Russell (1932)). More important is the recent burst of activity (reviewed by Harley (1978)) which shows that the vesicular — arbuscular endomycorrhizas associate with the roots of many crop plants (and wild vegetation). The external hyphae they develop act as " super root-hairs " and transport phosphate that is not accessible to the root itself to the fungus mycelium in the root, and so to the plant. This activity is certainly important for phosphate uptake; it *may* assist uptake of other nutrients. These studies and others on the role of microorganisms in the rhizosphere and in the body of the soil, must be pushed forward. Then will come the difficult job of integrating results with those of well-established work on solute movement.

Integration

In concluding their book, Nye and Tinker emphasise both the progress that has been made and the long road ahead. They say the topics are all old, but they have been freshened by new outlooks and new techniques: nutrition is now seen as a dynamic process, not a static situation of supply and demand. Workers are more ready to overlap traditional subject boundaries and to draw ideas from others. Modelling techniques have been used as tools to express these new trends and concepts which integrate physiology and soil science (formerly workers in these disciplines rarely communicated). But they warn: " It remains to be seen whether they can deal in detail with the truly formidable physical and chemical complexity of vegetation and soils. The mathematical techniques are now amply good enough for predicting any process we wish. The major factors impeding further progress are the inaccuracies of soil physical measurements, the natural heterogenity of soils, and the difficulty of predicting root development and properties when these are so closely linked with the growth of a whole plant or a community in a fluctuating environment."

The first full-scale discussion meeting on the soil-root interface was at Oxford in 1978 (Harley and Scott Russell (1979)); speakers gave clear accounts of subjects where good progress was being made and defined the many areas where our ignorance is an obstacle to progress. There was no account of the work of a truly multidisciplinary team such as I think is now essential for integrating individual efforts. Most of the papers are important reading, and there are pointers for future work in several of the wide-ranging reviews.

Pathways to Progress Through Field Studies

The urgent need is to identify causes of plant stress *in the* field and to devise methods of eliminating stress *in practice*. Stress may be chemical (shortage of nutrients, presence of toxins), physical (too much or too little water, wrong temperatures, mechanical blockages to root growth), or biological (harmful organisms, or absence of beneficial mechanisms). New scientific technology for visual appreciation and for measurement may have particular value for soil/root interface studies. Pedologists will have a vital role in attempts to integrate soil information on a particular site.

I will suggest a plan for field experiments later; but I would like to stress here the importance of having contrasts both in and between sites. If our main aim is to investigate desirable soil architecture for crops, we must study the arrangements under permanent vegetation (very old grassland) where the plants have already established the soil conditions appropriate to a managed climax. Most work on the root-soil interface has been in artificial conditions, or at best in arable soil. We will learn a great deal about desirable architecture by studying soil under grass; we can learn even more by studying the way in which this structure might be preserved when grassland is taken for crop production. We are unlikely to progress towards our aim of improved soil conditions for crops by studying soil *degradation*. But we may learn much by following the *improvement* in structure that herbage crops (and particularly legumes (Cooke and Williams (1972)) can cause. In all such work we must eschew traditional soil management, avoid using force to shatter soil aggregates and make full use of the concept that crops can now be sown and grown without stirring the soil—we must preserve each increment of improvement from each annual crop. (Man masters nature not by force, but by understanding (Bronowski).)

Pointers

Last year (Cooke 1979) I spoke to the British Society of Soil Science about some trends in the kinds of new information we were getting from field experiments and related studies, and some new ideas that seemed relevant in searching for ways of securing yields nearer to crop potentials. I will only repeat a terse paragraph from the paper:

" Nitrogen relationships are of vital importance in building yields and we have far to go in diminishing the losses that now occur (they will never be completely prevented in our climate), and in understanding soil and plant systems involving N. Reserves of all nutrients in soils, and particularly in subsoils, may be more effective in crop production than fertilizers applied in normal ways can be. In other words we cannot assume that ' fertilizer NPK ' can necessarily be equated to ' soil NPK '. Similarly there are conditions where accumulating a reserve of organic matter results in larger yields than can be achieved in a ' fertilizer only ' regime, perhaps because N from the organic source is more effective than N from fertilizer applied to surface soil. Work from other countries suggests that irrigation water may not be equivalent to reserves of water stored in soil and subsoil; this hypothesis needs testing in Britain. We have far to go in developing methods of identifying those aspects of soil structure that affect crop growth, and in measuring the effects of cultivating to various depths on structure, and on crop yield."

The three concepts resulting from work done in the last 50 years which should serve as a basis for new research on soil fertility are:

(i) Crops may now be completely protected from weeds, diseases and pests.

(ii) The potential yield of a healthy crop is set by its photosynthetic capacity. Achieving this demands that the fluxes of all nutrients and water to the root absorbing surfaces are at least equal to the needs of the crop at all stages of its growth. (With fertilizers to supply nutrients, and with irrigation available crops need suffer no deficiencies *provided* supplies are to the root zone, not simply to soil.)

(iii) It is no longer necessary to damage soil structure, destroy organic matter and diminish the soil population by ploughing and cultivating to control weeds. Crops grown in undisturbed soil will improve its architecture by the actions of their roots and through the activities of soil microorganisms and fauna.

Tools

I have stressed the importance of making full use of the new concepts developed in the last century and this—(1) that crop growth need not be limited by lack of water and nutrients, (2) that we do not have to destroy soil architecture in growing annual crops, and (3) that crop growth need not be limited by weeds or by soil-inhabiting pests; for the present soil-borne fungal diseases must be *avoided* in experiments by crop rotations. Our job is to ascertain the nature of the happenings below ground and to *measure* quantities and rate processes; at the same time we must observe the above ground plant processes—for which good models can already be made (Thornley, 1976). Wherever possible we must arrange that our measuring instruments do not interfere with the system; some measurements may involve destroying the site—but these can only refer to the static situation at the time of sampling.

Modern instruments have a formidable capacity to accumulate data at rates which themselves present problems. Recent reports from this Institute show that remote measurements can now be made by laser techniques of SO_2 and NO_x in the air at a considerable distance, yet we have not found ways to measure the changes in porosity of soil, and in the air and the water and its solutes, that surround a root that grows as the measurements are made. We need to give more attention to basic objectives and less to the accumulation of data which may lie unused in our files, or data banks, because we don't know what to do with it. There is another danger. The great advances in measurement techniques produce large numbers of figures, but isn't there a risk that we may get lost in the maze we create and fail to see our way forward? When I went to Rothamsted 40 years ago a skilled analyst was occupied for a whole week in determining potassium in six soil extracts by gravimetric methods. Now we can do as many, as accurately, in as many minutes; has our knowledge from this greatly increased capability advanced proportionately? When we had only six figures we made the maximum use of them, we were very careful to analyse only relevant material, and we had time to think about interpretation. Are we now too busy with technicalities to give attention to fundamental matters?

Interactions. It is often forgotten that while the main effect of treatment may *decrease* as quantity of input increases, interactions often *increase* with increasing inputs. Interactions that are important are not only between nutrients, they occur between all inputs to crop production.

Input-output relationships. We need to know more about the *form* of the relationship between an input and its effect on a crop characteristic such as yield. There is increasing evidence that for practical purposes relationships are often linear. I now ask two questions—(1) why are they not always linear?; (2) if relationships are truly curvilinear in a single experiment, or closely related group of experiments, may it not mean that an interaction with an unrecognised factor is occurring and this possibility needs investigation?

Pedology. As important as any of these tools is the help and understanding which pedologists will bring to this research. Their search for principles to aid description and classification gives them a unique ability to see the soil profile as a whole. I would like to emphasise the value of developments in survey and classification in the USA summarised by Cline (1977). The new ideas resulting from many years of thought and international discussion are set out in " Soil Taxonomy " by the Soil Survey Staff (1975); the book gives a distinguished account of the philosophical development of taxonomy and classification. The application of the US System to British soils has been appraised by Ragg and Clayden (1973); they stress its value in careful definitions of diagnostic criteria, as well as its limitations.

The system merits further study for, as Cline says, it has "required a remarkable transformation from qualitative to quantitative data gathering by the field force. It defines class limits in quantitative terms." Further development of the quantitative approach to soil description and classification will be needed as we proceed to integrate field work on soils more fully into research programmes. It will also be needed by all who use our inventories—farmers, agronomists or engineers.

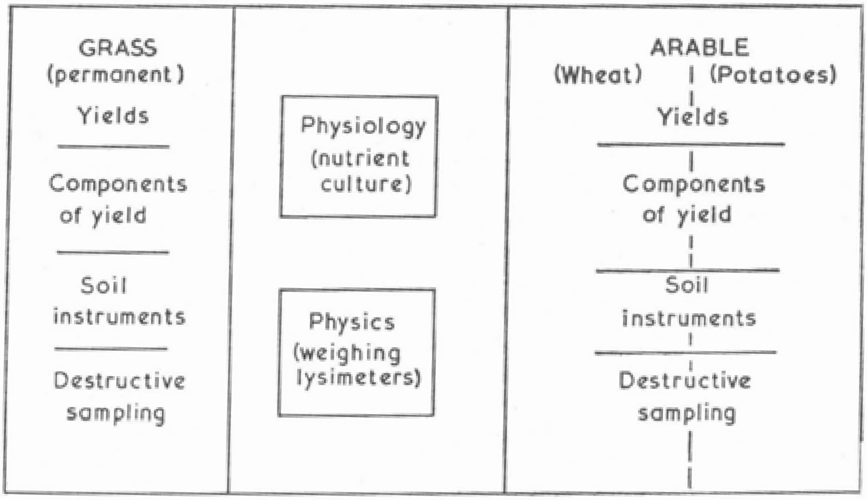
Modelling. In the present emphasis on modelling we sometimes forget that the representation of situations or events by mathematical equations is an old trade. Crowther (1953) pointed out 25 years ago that soil formation factors had been set up as differential equations, "but as the equations cannot be solved, this doesn't take us much further."

Models are mathematical representations of relations between the components of a system. They should be applied to check whether we have identified and correctly measured all the factors that affect crop growth; they should be dynamic. The failure of a model means that we do not completely understand the system. When successful we will have a generally applicable basis for extending the information from our research on one site to another site where local conditions can be described mathematically. Modelling above ground parts of plants has been successful because all dimensions and components of plants and the homogenous aerial environment can be measured. However we are concerned with roots in soil; roots are inaccessible, soil is heterogenous, and we still have much to learn about processes of root growth and about the ways in which soils supply water and nutrient ions.

The components of our present research are good, but, as with a machine, we don't know if the whole system will work until we have put the parts together and have seen (1) if they fit, (2) if they work in harmony, (3) whether some components are missing. As I see it this is the reason why we begin model building. The aim is to describe the system by numerical components because it cannot be studied directly; we hope that our understanding will be improved by unifying the separate concepts. The test of the model ("will it go?") is by seeing if it can predict correctly a parameter (yield) that we can measure. If it works we can take it to other sites; if it fails we must find the weakest link and strengthen the model by more intensive work. Models should be simple; complexity may mean we have failed to make up our minds on the basic principles of the system. Inserting parameters for which we have no data blocks progress. We will have to distinguish between important and unimportant; we may have to reject accepted theories and statements (they may be unproved!). All measurements are subject to error; the more parameters we introduce the greater the total error, with many parameters in a model most of the variation may come from chance alone.

In the 1821 Edition of his book Humphrey Davy made observations that are still relevant. He wrote that no general principles could be laid down on the comparative merits of different systems of cultivation unless the chemical nature of the soil and the physical circumstances to which it is exposed are fully known. "Nothing is more wanting in agriculture, than experiments in which all the circumstances are minutely and scientifically detailed. This art will advance with rapidity in proportion as it becomes exact in its methods . . . The results of truly philosophical experiments in agricultural chemistry would be of more value in enlightening and benefiting the farmer, than the greatest possible accumulation of imperfect trials conducted merely in the empirical spirit. In proportion as science advances all the principles become less complicated, and consequently more useful." Finally, science will "substitute sound and rational principles, for vague, popular prejudices."

SITE FOR SOIL RESEARCH, 1980-2000 A.D.



Concluding: A Plan for Soil Research

In suggesting a plan for future soil research, I have tried to stick to the theme that I have developed—that the main thrust must be to understand completely the root/soil relationships that govern soil fertility. From this knowledge we will develop scientific principles of soil fertility management so that when water and nutrient inputs are fully supplied, crop yields are only limited by the photosynthetic process. Only then can we claim to be in control of the soil-plant system. May I remind you that the *purpose of management* is to *avoid surprises*!

To progress we need to assemble a team under leadership which has vision and charisma. The objectives must be clear and the working atmosphere increasingly stimulated by success. Humdrum routine "stamp-collecting" of data and needless elaboration of technology will have no place. I do think the group must have its basis in field work. For a start I see a site on heavy drained soil offering two contrasts. It should provide old grassland capable of producing near to the potential established by Cooper (1970) when supplied with nutrients and water. Old arable land alongside would grow a cereal and a root storage crop. The experiments should not be complicated by comparisons and tests on surface cultivation systems; although practically important, they can be done elsewhere. But it may be necessary to provide contrasts of undisturbed arable sites with others were subsoil horizons are thoroughly stirred and enriched with nutrients by mechanical means. The field should provide whole profiles that are physically different because of different management systems. The effects of these differences on crop yield will, of course, be measured but the main aim will be to measure physical, chemical and biological parameters related to stress on plant roots. Sections of the contrasted areas will be fully instrumented, other sections used for destructive sampling. Physiologists may need large tanks for nutrient culture of crops in an inert medium to determine physiological potential at the site. Physicists studying water relations in subsoil may require weighing lysimeters such as were used long ago by King (1892) and described more recently by Morris (1959).

When we understand processes of root growth, nutrient and water uptake, and the effects of biological processes on soil architecture, we will be able to plan for the needs of our crops. In the rare cases where soil properties seem ideal (as where farmers have already achieved potential crop yields) we will know how to maintain these properties and so be able to *repeat* successes in successive years. In the more common circumstances where properties are not ideal we will develop management and cropping systems that improve soil architecture by the action of plant roots and their associated flora and fauna. Our aim is then to reach an ecological climax for cultivation on any site that suits the crops to be grown.

I am well aware that my proposals involve difficult and long-term work that demands faith in its ultimate success. It might seem more convenient and congenial to do much in laboratory and glasshouse. But I believe that concepts of processes in the soil/root interface are now well enough advanced to receive the challenge of application in the field. Fifty years ago technical knowledge of peat land management received its challenge through application on the Island of Lewis; the pioneers succeeded. I believe that the objectives for the future of soil research that I have outlined would also have the approval of the founder of this Institute, and of its first Director.

References:

Austin, R. B. (1978). Actual and potential yields of wheat and barley in the United Kingdom. ADAS Quarterly Review, **29**, 76-87.

Avery, B. W. (1962). Soil type and crop performance. Soils and Fertilizers, **25**, 341-344.

Baker, J. R. (1979). In the cause of freedom in science. New Scientist, 12 July, 1979, pp. 108-9.

Balfour, E. B. (Lady) (1975). The Living Soil and the Haughley Experiment. London: Faber and Faber.

Bridges, E. M. (1978). Interactions of soil and mankind in Britain. Journal of Soil Science, **29**, 125-139.

Bullock, P. and Murphy, C. P. (1976). The microscopic examination of the structure of subsurface horizons of soils. Outlook on Agriculture, **8**, 348-354.

Childs, E. C. (1969). An introduction to the physical basis of soil water phenomena. London: Wiley.

Clark, F. E. (1977). Soil microbiology — it's a small world. Soil Science Society of America Journal, **41**, 238-241.

Cline, M. G. (1977). Historical highlights in soil genesis morphology and classification. Soil Science Society of America Journal, **41**, 250-254.

Cooke, G. W. (1954). Recent advances in fertilizer placement. II Fertilizer placement in England. Journal of the Science of Food and Agriculture, **9**, 429-440.

Cooke, G. W. (1979). Some priorities for British soil science. Journal of Soil Science, **30**, 187-213.

Cooke, G. W. and Williams, R. J. B. (1972). Problems with cultivations and soil structure at Saxmundham. Report of Rothamsted Experimental Station for 1971, Part 2, pp. 122-142.

Cooper, J. P. (1970). Potential production and energy conversion in temperate and tropical grasses. Herbage Abstracts, **40**, 1-15.

Crowther, E. M. (1953). The sceptical soil chemist. Journal of Soil Science, **4**, 107-122.

Dagg, M., Blackie, J. R. and Alose, N. O. (1969). Crop water use. Record of research, Annual Report 1968 East African Agriculture and Forestry Research Organisation, Nairobi, pp. 19-23.

Emerson, W. W., Bond, R. D. and Dexter, A. R. (1978). Modification of soil structure. Chichester: Wiley.

Endeavour (1979). Europe on the drawing board. Endeavour **3** (2), p. 47.

F.A.O. (1970-76). Production year books for 1970-1976. Vols. 24-30. Rome, Italy; F.A.O.

Gardner, W. H. (1977). Historical highlights in American soil physics, 1776-1976. Soil Science Society of America Journal, **41**, 221-229.

Gibson, J. E. (1979). Performance evaluation of academic research. Science, **206**, 407.

Greenland, D. J. (1977). Soil damage by intensive arable cultivation: temporary or permanent? Philosophical Transactions of the Royal Society of London B **281**, 193-208.

Greig, R. (Sir) (1938). Preface. Macaulay Institute for Soil Research. Collected Papers, Vol. 1, pp. 5-7.

Harley, J. L. (1978). Ectomycorrhizas as nutrient absorbing organs. Proceedings of the Royal Society of London B, **203**, 1-21.

Harley, J. L. and Scott Russell, R. (1979). The soil-root interface. London: Academic Press.

Henderson, W. M. (Sir) (1977). Science policy for agriculture. Macaulay Institute for Soil Research. Annual Report for 1975-76, No. 46, pp. 114-120.

Heslop-Harrison, J. (1978). Research, crop production and policy. The Bewley Memorial Lecture. Annual Report Glasshouse Crops Research Institute 1977 (Supplement), 13 pp.

Hoagland, D. R. (1931). Absorption of mineral elements by plants in relation to soil problems. Plant Physiology, **6**, 373-388.

Jacks, G. V. (1963). The biological nature of soil productivity. Soils and Fertilizers, **26**, 147-150.

J.C.O. (1975). Second Reports of the Boards of the Joint Consultative Organisation. London, HMSO.

J.C.O. (1977). Reports of the Boards of the Joint Consultative Organisation and Responses from the Sponsors. London, HMSO.

Keen, B. A. (1925). The physicist in agriculture with special reference to soil problems. Physics in Industry, 29-63.

Keen, B. A. (1931). The physical properties of the soil. London, Longmans, Green & Co.

Keen, B. A. and Russell, E. W. (1937). Are cultivation standards wastefully high? Journal of the Royal Agricultural Society, **98**, 53-60.

King, F. H. (1892). Investigations relating to soil moisture. Agricultural Experiment Station; Eighth Annual Report, University of Wisconsin, pp. 100-134.

Kubiena, W. L. (1964). Role and mission of micromorphology and microscopic biology in modern soil science. In: Soil micromorphology. Ed. A. Jongerius. Amsterdam: Elsevier, pp. 1-13.

Ministry of Agriculture, Fisheries and Food (1970). Modern farming and the soil. Report of Agricultural Advisory Council on soil structure and soil fertility. London, HMSO.

Moffat, J. R. (1975). Cultivation-weedkiller experiment, Rothamsted, 1961-72. Report of Rothamsted Experimental Station for 1974, Part 2, pp. 155-170.

Morris, L. G. (1959). A recording weighing machine for the measurement of evapotranspiration and dewfall. Journal of agricultural engineering research, **4**, 161-73.

Morrison, P. (1979). Termites and telescopes. Listener, **102**, pp. 234-238.

Murphy, C. P., Bullock, P. and Biswell, K. J. (1977). The measurement and characterisation of voids in soil thin sections by image analysis. Part 2. Applications. Journal of Soil Science, **28**, 509-518.

Nye, P. H. and Tinker, P. B. (1977). Solute movement in the soil-root system. Oxford: Blackwell.

Ogg, W. G. (1938). The Macaulay Institute for Soil Research. Collected Papers, Vol. 1; No. 1, pp. 1-10; No. 2, pp. 1-10.

Ogg, W. G. (1933). Developments in soil science and recent British contributions to its literature. Scottish Geographical Magazine, **49**, 37-42.

Penman, H. L. (1966). Evaporation and related studies. Report of Rothamsted Experimental Station for 1965, pp. 31-34.

Pickering, S. U. (1917). The effect of one plant on another. Annals of Botany, **31**, 181-7.

Ragg, J. M. and Clayden, B. (1973). The classification of some British soils according to the comprehensive system of the United States. Soil Survey Technical Monograph No. 3.

Robinson, G. W. (1932). Soils, their origin, constitution, and classification. London: Murby.

Royal Agricultural Society of England (1979). Barley '79 yields. NAC News, September 1979, p. 2.

Russell, E. J. (1932). Soil conditions and plant growth. 6th Edition. London: Longmans, Green & Co.

Russell, E. W. and Keen, B. A. (1938). Studies in soil cultivation. VII. The effect of cultivation on crop yield. Journal of Agricultural Science, Cambridge, **28**, 212-233.

Russell, E. W. (1956). The effects of very deep ploughing and of subsoiling on crop yields. Journal of Agricultural Science, Cambridge, **48**, 129-144.

Russell, E. W. (1973). Soil conditions and plant growth. 10th Edition. London: Longmans.

Russell, E. W. (1978). Soil survey methodology and agriculture. Macaulay Institute for Soil Research. 1976-77 Annual Report No. 47, pp. 120-133.

Russell, R. Scott (1977). Plant root systems. London: McGraw-Hill.

Sands, W. A. (1977). The role of termites in tropical agriculture. Outlook on Agriculture, **9**, 136-143.

Sawhill, J. C. (1979). The role of science in higher education. Science, **206**, (No. 4416).

Slater, (Sir) W. (1963). Foreword. Macaulay Institute for Soil Research. Collected Papers, Vol. VI, p. 3.

Soil Survey Staff (1975). Soil taxonomy: A basic system of soil classifification for making and interpreting soil surveys. Agricultural Handbook No. 436. USDA. US Government Printing Office, Washington, DC.

Soils Science Society of America (1977). Bicentennial papers. Soil Science Society of America Journal, **41**, 221-265.

Stewart, A. B. (1965). Soil in the field and in the laboratory. Journal of Soil Science, **16**, 171-182.

Thornley, J. M. H. (1976). Mathematical models in plant physiology. London: Academic Press.

Viets, F. G., Jr. (1977). A perspective on two centuries of progress in soil fertility and plant nutrition. Soil Science Society of America Journal, **41**, 242-249.

Walker, N. (Editor) (1975). Soil microbiology. London: Butterworths.

Warington, R. (1900). Physical properties of soil. Oxford: Clarendon Press.

Williamson, W. T. H. (1959). The discipline of soil science. Journal of Soil Science, **10**, 1-4.

LIST OF PUBLICATIONS, 1978-79

1020* ANDERSON, G. Bacterial DNA in soil; comment on a paper by Torsvik and Goksoyr (1978). *Soil Biol. Biochem.*, 1979, **11**, 213.
This note comments on some of the results and observations of Torsvik and Goksoyr regarding the content of bacterial DNA in soils.

1027 ANDERSON, G. Soil organic chemistry. *Education in Chemistry*, 1979, **16**, 35-37.
A short account of the chemical nature and properties of soil organic matter and of the methods used to examine it, written for teachers of chemistry.

BACHE, B. W. Activity ratio. In: *Encyclopaedia of Soil Science, Part 1.* Edited by R. W. Fairbridge and C. W. Finkl. London, Academic Press, 1979, 4-8.
The solution concentration of any ion in equilibrium with a soil is altered by incidental factors such as the soil: solution ratio and the addition of electrolyte. Within certain limits, variations in these factors do not affect the results if activity ratios and products are used to express soil solution composition. This review discusses the theory underlying the activity ratio concept, the ratio law, the measurement and use of activity ratios, and the relation of activity ratio to cation exchange equilibria.

BACHE, B. W. Base saturation. In: *Encyclopaedia of Soil Science, Part 1.* Edited by R. W. Fairbridge and C. W. Finkl. London, Academic Press, 1979, 38-42.
The ability of soils to adsorb base cations, principally calcium, magnesium, potassium, sodium and ammonium ions, in exchangeable forms is important in the supply of these nutrients to plants. In neutral soils the adsorption complex is saturated with such cations, but in acid soils it contains hydrogen and aluminium ions and is unsaturated with base cations. This review briefly describes modern views of soil acidity, cation exchange, base saturation, and the relationship of base saturation to pH and to soil formation.

BACHE, B. W. Chemical composition. In: *Encyclopaedia of Soil Science, Part 1.* Edited by R. W. Fairbridge and C. W. Finkl. London, Academic Press, 1979, 67-70.
The criteria needed for the chemical characterization of soils, and the numerical values commonly found, are discussed under the headings: the organic fraction, water-soluble components, carbonates, primary minerals, secondary minerals, cation exchange properties, trace elements and fertility analyses.

BACHE, B. W. Soil reaction. In: *Encyclopaedia of Soil Science, Part 1.* Edited by R. W. Fairbridge and C. W. Finkl. London, Academic Press, 1979, 487-492.
The so-called reaction of soil, expressed in terms of a pH number, is probably the most informative single chemical measurement that can be made on it, because it relates closely to its genesis, its composition and to the availability of plant nutrient elements. This article explains the pH concept and its application to soil, describes methods of measurement, outlines buffering mechanisms that control soil pH, and briefly discusses the relationships between pH and soil processes.

BACHE, B. W. Soil solution. In: *Encyclopaedia of Soil Science, Part 1.* Edited by R. W. Fairbridge and C. W. Finkl. London, Academic Press, 1979, 497-498.
The aqueous solution of soils is the immediate source of nutrients for growing crops. This review defines what is meant by soil solution, explains how it can be separated from the bulk soil, and quotes examples of its chemical composition.

* 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, which are available free from the Librarian, Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen, AB9 2QJ.

BACHE, B. W. and SCOTT, N. M. Sulphur emissions in relation to sulphur in soils and crops. In: *Sulphur Emissions and the Environment.* London, Society of Chemical Industry, 1979, 243-254.
This review describes the soil sulphur cycle, the forms and amounts of sulphur in soils and the sulphur needs of crops. The importance of sulphur deposition from the atmosphere as a source of crop sulphur is then assessed in relation to the sulphur supplied by soils and fertilizers. It concludes that where fertilizers containing only traces of sulphur are used, atmospheric sources become important. Under some conditions sulphur from fertilizers is required to produce optimum yields.

1016 BACON, J. R. and URE, A. M. The correction of interference effects in the determination of the rare earth elements and hafnium by spark source spectrometry. *Anal. Chim. Acta.,* 1979, **105**, 163-176.
Super-positional interferences from oxide ion species have been shown to cause significant errors in the spark source mass spectrometric determination of hafnium and the rare earth elements, when aluminium is used as the conducting matrix for samples such as rocks and soils. A mathematical correction procedure is described in which corrections are made in any particular exposure using intensity measurements derived from that exposure alone. Its effectiveness is demonstrated for the USGS Standard Rocks BCR-1, AGV-1 and G-2.

1071 BARTLEY, D. F., HURST, T., NORRIS, J. D. and WEST, T. S. Thermostated electrodeless discharge lamps in atomic spectroscopy. *Rev. Anal. Chem.,* 1978, **4**, 19-59.
The construction of microwave-excited electrodeless discharge lamps as sources of intense atomic line radiation for the stimulation of atomic fluorescence for trace metal analysis is described. Attention is paid to construction techniques, e.g. filler gas pressure, amount of fill material, temperature and power of operation, multi-element lamps, etc., and the detection limits with a graphite rod electrothermal atomizer are described for eight elements including Cu, Pb, Ag, Sn and Zn.

BERROW, M. L. and BURRIDGE, J. C. Sources and distribution of trace elements in soils and related crops. In: *Proc. Conf. Management and Control of Heavy Metals in the Environment.* London, 1979, 304-311.
The sources of trace elements in soils are considered in two groups: (i) parent material and beneficial agricultural materials for example, lime, fertilizers, manure, herbicides, fungicides, irrigation water, and (ii) potentially deleterious materials such as sewage sludge, municipal compost, fly ash, mine waste and atmospheric deposition. The relative contributions from these sources are discussed. Soil conditions affecting the availability of trace elements to plants, and also the influence on plant content of vegetal factors, including species differences and seasonal change, are described. Some effects of adding sewage sludges with abnormally high metal contents on soil and plant composition, at two sites on different soil types, are reported and discussed. Several ways in which management practice may ameliorate the toxic effects in soils arising from heavy metal contamination are indicated.

994 BERROW, M. L., WILSON, M. J. and REAVES, G. A. Origin of extractable titanium and vanadium in the A horizons of Scottish podzols. *Geoderma,* 1978, **21**, 89-103.
The A horizons of Scottish podzols often contain unusually large amounts of Ti and V extractable by EDTA. The Ti minerals, which are generally considered to be inert and resistant to weathering, show clear evidence of chemical and possibly physical weathering. This leads to an accumulation of Ti in the fine fractions probably as discrete particles, but there is little or no evidence of downward leaching. Vanadium released by weathering is also accumulated in the fine fractions probably as an exchangeable cation. Most of the V extracted from the soils and from clay fractions has been shown to be in the form of vanadyl, $(VO)^{2+}$, cation.

BIBBY, J. S. "An evaluation of the land use capability map series for Scotland" by D. R. Macgregor: a note. *Scottish Geographical Mag.* 1978, **94**, 143-144.

1073 BOUND, E. A., NORRIS, J. D., SANZ-MEDEL, A. and WEST T. S. The atomic absorption spectrometric determination of palladium with a carbon-filament electrothermal atomizer. *Anal. Chim. Acta.* 1979, **104**, 385-387.

Palladium may be determined by carbon rod atomic absorption spectrometry at 244.79 nm with a sensitivity of 1.6×10^{-8}g cm^{-3}. The interference of elements such as Al, Ca, Co, Fe, Mg, Ni, P, Pb and S become appreciable when they are present at 1000-fold greater concentrations.

1047 BRACEWELL, J. M., ROBERTSON, G. W. and LOGAN, J. Variability of organic matter and exchangeable cations within the A_2 horizon of an iron podzol. *J. Soil Science.* 1979, **30**, 327-332.

Replicate sampling of the same soil feature at different sites was carried out for a representative range of soil properties. Many of these show the major proportion of their total variation at distances of less than a metre thus markedly limiting the interpretation of data from single samples. Properties reflecting base status and humus type show in addition a significant variation over distances of the order of a kilometre.

992 BUCKLEY, H. A., JOHNSON, L. R., BEVAN, J. C., BROWN, K. M. (Dept. Mineral., Br. Mus. Nat. Hist.) and FARMER, V. C. Glauconite and celadonite: two separate mineral species. *Mineralog. Mag.* 1978, **42**, 373-382.

A distinction can be made between two series of ferruginous mica on the basis of chemical compositions, X-ray diffraction patterns, infrared spectra and crystal morphology. The glauconite group is of low temperature origin, whereas the celadonite group is of hydrothermal origin.

1007 BURRIDGE, J. C. and HEWITT, I. J. A simple procedure for ^{15}N determination in relatively large samples by emission spectrometry. *Comm. Soil Sci. Plant Anal.* 1978, **9**, 865-872.

Discharge tubes containing argon, and NH_3 separated from atmospheric N_2 by condensation in a liquid-nitrogen-cooled trap, are used to determine $^{15}N:^{14}N$ ratios in ammonium solutions. Reduction of NH_3 to N_2 during sample preparation is not required; the dissociation of NH_3 in the discharge tube produces sufficiently intense N_2 band spectra for the isotope analysis. The method can be readily applied to the analysis of ammonium solutions derived from Kjeldahl digests of plant material.

CHESHIRE, M. V. Polysaccharides in soils. In: *Encyclopaedia of Soil Science, Part I.* Edited by R. W. Fairbridge and C. W. Finkl. London, Academic Press, 1979, 390-396.

A brief summary of the current knowledge of the amounts, composition and function of polysaccharides in soils is presented.

1046 CHESHIRE, M. V., BRACEWELL, J. M., MUNDIE, C. M., ROBERTSON, G. W., RUSSELL, J. D. and FRASER, A. R. Structural studies on soil polysaccharide. *J. Soil Sci.* 1979, **30**, 315-326.

Soil polysaccharide is thought to be a mixture derived from plant residues and microbial materials, but it is not known exactly what proportion arises from each source. Some insight into the chemical structures of polysaccharides present may be obtained by analysis of the hydrolysis products after methylation of the soil polysaccharide. The products thus obtained suggest that although soil polysaccharide has diverse origins there is a large contribution from plant sources.

CHESHIRE, M. V., MUNDIE, C. M. and SHEPHERD, H. Transformation of carbohydrate constituents of grass during decomposition in soil. *J. Sci. Fd. Agric.* 1979, **30**, 330.

Experiments in which ^{14}C-labelled fresh ryegrass plants are incubated in soil for periods up to one year have been conducted to study the persistence of plant carbohydrates in soil. After a year about a fifth of the plants' glucose and arabinose and a quarter of the xylose components appear to remain undecomposed.

989 CHESHIRE, M. V., SPARLING, G. P., MUNDIE, C. M., SHEPHERD, H. and MURAYAMA, S. (Nat. Inst. Agric. Sci., Tokyo). Effect of temperature and soil drying on the transformation of (^{14}C) glucose in soil. *J. Soil Sci*. 1978, **29**, 360-366.

Previous studies at this Institute on the effect of temperature on the transformation of glucose in soil used pre-dried soil. It has now been shown that the increased synthesis of xylose observed at 5°C over that at 20°C with pre-dried soil is not observed when fresh soil is used. The xylose synthesis can be related to the metabolism of yeasts and their relative numbers in relation to bacteria. Bacteria appear to be inhibited at low temperature in pre-dried soil.

1013 CHILDS, C. W., GOODMAN, B. A. and CHURCHMAN, G. J. Application of Mössbauer spectroscopy to the study of iron oxides in some red and yellow/brown soil samples from New Zealand. *International Clay Conf., 1978*. Edited by M. M. Mortland and V. C. Farmer. Amsterdam, Elsevier, 1979, 555-565.

Mössbauer spectroscopy has been used to characterise the secondary Fe oxides in some red (Munsell hue in the range 1OR-5YR) and yellow/brown (7.5YR-2.5Y) soil samples from New Zealand. Dithionite/citrate/bicarbonate treatment of all samples produced whitish-grey to grey residues indicating that the colouring material was present in the "free Fe oxide" fraction of the soils. At room temperature the spectrum of each red sample has a magnetic hyper-fine component attributable to hematite. This is absent from the spectra of all yellow/brown samples. At 77K further magnetic hyperfine components are evident in some red samples and in all yellow/brown samples, and are attributable to goethite of very small particle size (superparamagnetic) and/or akaganeite. The Munsell designation can be used to relate colour to the concentration of free Fe oxides with reasonable accuracy (+25%) for the red samples, but not the yellow/brown samples. In addition, the increasing intensity of redness, judged subjectively, is closely related to increasing concentration of hematite in the red samples.

993 CRADWICK, P. D. General theory of one-dimensional scattering of X-rays from interstratified clay minerals. *N.Z. Jl. Sci*. 1978, **21**, 409-411.

Interstratified clay minerals frequently occur in soils and their X-ray diffraction patterns are usually interpreted on the basis of calculated diffraction intensities yielded by a suitable model. The general theory of such calculations is presented.

977 CRADWICK, P. D. and WILSON, M. J. Calculated X-ray diffraction curves for the interpretation of a three-component interstratified system. *Clay Minerals*, 1978, **13**, 53-65.

Interstratified clay minerals are common in soils and frequently form during the pedogenic weathering of mica. It is often difficult to interpret the X-ray diffraction patterns of such material, especially when more than two components are involved. In this paper a series of calculated curves are presented for interstratified mica-vermiculite-montmorillonite; these should be of practical use where interpretative problems are encountered.

1039 DeKOCK, P. C., CHESHIRE, M. V., MUNDIE, C. M. and INKSON, R. H. E. The effect of galactose on the growth of lemna. *New Phytol*. 1979, **82**, 679-685.

Lemna gibba (duckweed) has been grown axenically in nutrient media. With 0.1% glucose the plants grew well, but 0.1% galactose was toxic, an effect made worse by adding ethanol at 0.1%; addition of glucose reduced galactose toxicity. Galactose-1-phosphate and galactose-6-phosphate produced no signs of toxicity. Large amounts of starch accumulated in the affected plants, and when fed ^{14}C galactose, both glucose and xylose were well labelled. Inorganic analyses of the affected fronds were typical of dormant tissue, with high iron and calcium and lower potassium and phosphorus contents showing. Current theories of galactose toxicity are discussed in the light of these findings.

1048 DeKOCK, P. C., HALL, A. and INKSON, R. H. E. Active iron in plant leaves. *Ann. Bot.* 1979, **43**, 737-740.

Extraction of the "active" iron fraction with etherized tenth molar hydrochloric acid from plant leaves is laborious. It is shown that the ratio of total phosphorus to total iron correlates very well with the "active" iron fraction and can be used as an index of metabolically active iron.

1033 DeKOCK, P. C., HALL, A. and INKSON, R. H. E. Nutrient distribution in the potato tuber in relation to soil pH. *Ann. Bot.* 1979, **43**, 299-304.

The distribution of the major nutrients in cores of potato tubers obtained from soil plots maintained at nominal pH values ranging from 4.5 to 7.5 was examined. Of these calcium showed the most pronounced changes increasing with increased soil alkalinity, while other constituents showed changes which could be related to those of calcium. It appeared that certain ratios were at a maximum at pHs where optimum growth is usually attained.

1029 DeKOCK, P. C., HALL, A. and INKSON, R. H. E. A study of peroxidase and catalase in the potato tuber. *Ann. Bot.* 1979, **43**, 295-298.

Potato tubers, *cv*. Majestic, were obtained from the pH plots of the Craibstone Experimental Farm of the North of Scotland College of Agriculture. Cores were struck from heel to rose ends and these then sub-divided into 16 equal parts. Determinations of peroxidase and catalase activities were made on these consecutive pieces and regression equations computed from the values obtained. It could be demonstrated that the ratio of the activities of peroxidase to catalase was at a maximum in tubers grown in soil pHs 5.5 to 6 and decreased towards either end of the pH range. It is in this pH range that the growth of the potato reaches optimum values.

1049 DeKOCK, P. C., HALL, A., INKSON, R. H. E. and ROBERTSON, R. A. Blossom-end rot in tomatoes. *J. Sci. Ed. Agric.* 1979, **30**, 508-514.

To study Blossom-End Rot (BER) of tomatoes, plants were grown in peat modules with different amendments of lime and fertilizer. Nitrogen in the nutrient solutions was added as ammonium, nitrate, ammonium nitrate or urea. Incidence of BER was severe with the ammonium ion, less so with ammonium nitrate and urea and absent with nitrate. Higher levels of calcium reduced the disorder.

DeKOCK, P. C., HALL, A., NAYLOR, A. and INKSON, R. H. E. Nitrate reduction in plant leaves in relation to calcium. *Proc. 6th Long Ashton Symp. Nitrogen Assimilation of Plants, 1979.*

Even though the metal elements present in the enzyme nitrate reductase are iron and molybdenum, its activity in cauliflower and cabbage has been shown to depend on the calcium content of the nutrient solution as well as on the amount of nitrate added.

1005 DeKOCK, P. C., VAUGHAN, D. and HALL, A. Effect of abscisic acid and benzyladenine on the inorganic and organic composition of the duckweed, lemna gibba L. *New Phytol.* 1978, **81**, 505-511.

The growth inhibitor abscisic acid (ABA) causes the fronds of duckweed (Lemna gibba) to become dormant and fill with starch. The growth hormone, benzyladenine (BA) will counteract this dormancy. The mineral changes induced in the fronds by ABA are typical of dormant tissues having both low phosphorus-iron and low potassium-calcium ratios. BA causes these ratios to revert to normal values.

DUNCAN, N. A. The moisture regimes of six soils of the Central Lowlands of Scotland. *J. Soil Sci.* 1979, **30**, 215-223.

Quantitative data on the periodicity of waterlogging are presented for six soil series which are widespread throughout the Central Lowlands of Scotland. Metric suctions, the correlations between borehole and tensiometer data, and the limitations of piezometers are also discussed.

1045 EDMONDS, T. E. A microcomputer-based data acquisition and processing system for electrochemical analysis. *Anal. Chim. Acta.*, 1979, **108**, 155-160. An approximately four-fold improvement in the detection limit for the differential pulse polargraphic determination of Mo is achieved, by using this microcomputer-based data acquisition and processing system. Other advantages include the removal of interference from Cu, by background subtraction, and rapid and simple interfacing with other electro-chemical techniques, such as tripping voltammetry and controlled potential coulometry. The new detection limit for Mo is 2.7×10^{-4} ppm.

FARMER, V. C. Infrared spectroscopy in mineral and inorganic chemistry *Proc. 6th Ceram. Chem. Conf. on Silicate Analysis, Brit, Ceram. Res. Assoc. Spec. Publ.* **98**, 1979, 101-122.
The contributions that infrared spectroscopy can make to the characterisation of minerals and mineral products are compared with those of X-ray diffraction, and illustrated with examples.

FARMER, V. C. The role of infrared spectroscopy in a soil research institute; characterization of inorganic materials. *European Spectroscopy News*, 1979, **25**, 25-27.
Applications of infrared spectroscopy to the characterization of soil minerals at the Macaulay Institute are briefly reviewed in an article of general interest to spectroscopists.

FARMER, V. C. Water on particle surfaces. In: *The Chemistry of Soil Constituents.* Edited by D. J. Greenland and H. H. B. Hayes. Chichester, Wiley, 1978, 405-448.
The strength of binding of the first molecular layer of water to the surface of soil particles determines the wettability of soils, and plays an important role in the release and retention of fertilisers and pesticides. The chemistry of the interactions of water with both inorganic and organic soil components is reviewed here in the light of modern theories of the structure of liquid water and aqueous solutions.

1012 FARMER, V. C. and FRASER, A. R. Synthetic imogolite, a tubular hyroxyaluminium silicate. *International Clay Conf., 1978.* Edited by M. M. Mortland and V. C. Farmer. Amsterdam, Elsevier, 1979. 547-553.
The conditions necessary for the formation of the ordered tubular structure of the hydroxyaluminium silicate, imogolite, are surveyed, and the product is characterized by electron microscopy, electron diffraction, X-ray diffraction and infrared spectroscopy. The work illuminates the formation of allophane and imogolite in soils, and raises questions concerning the form of aluminium in acid soil solutions. It makes available a possibly useful inorganic polymer of regular structure, high surface area, defined porosity, and exceptional gel-forming characteristics.

1050 FARMER, V. C., FRASER, A. R. and TAIT, J. M. Characterization of the chemical structures of natural and synthetic aluminosilicate gels and sols by infrared spectroscopy. *Geochim. Cosmochim, Acta,* 1979, **43**, 1417-1420.
In spite of the importance of aluminosilicate gels as reactive soil components, their chemical structures have proved difficult to characterize, largely because of inapplicability of diffraction techniques to materials with only short-range order. It is here shown that infrared spectroscopy in the 300-1400 cm^{-1} range reveals major differences in structure between aluminosilicate gels or sols formed in acid conditions ($pH<5$) and those formed in neutral or alkaline conditions ($pH>6$), the former having structures related to imogolite and the latter structures related to hydrous felds-pathoids. Natural allophanes with these structures are shown to exist.

996 FARMER, V. C., FRASER, A. R., TAIT, J. M., PALMIERI, F., VIOLANTE, P., NAKAI, M. and YOSHINAGA, N. Imogolite and proto-imogolite in an Italian soil developed on volcanic ash. *Clay Miner.*, 1978, **13**, 271-274.
Imogolite has been identified in small amounts in clays from a soil profile developed on pyroclastics of tephrite-bassanite composition. The major

part of the fine clay was an allophanic material termed proto-imogolite, characterized by an infrared spectrum with some of the features given by imogolite, including a well-developed band at 346 cm^{-1}. Similar products have been obtained in the laboratory.

1042 FARMER, V. C., SMITH, B. F. L. and TAIT, J. M. The stability, free energy and heat of formation of imogolite. *Clay Miner.*, 1979, **14**, 103-107.
It is now recognised that imogolite and related reactive aluminium silicates are widely distributed in soils. Measurement of the equilibrium values of silica in solution over imogolite and boehmite, combined with thermodynamic considerations, define the conditions under which imogolite is likely to be stable, or to be converted to halloysite or aluminium hyroxides.

987 FARMER, V. C. and WARNE, S. St. J. Infrared spectroscopic evaluation of iron contents and excess calcium in minerals of the dolomite-ankerite series. *Amer. Mineral.*, 1978, **63**, 779-781.
Evaluation of the dolomite content of carbonate deposits and the placing of a ferroan dolomite within the dolomite-ankerite isomorphous series are of importance for the agricultural use of dolomite as a source of magnesium and as a soil pH regulator. Infrared spectroscopy is shown to be a convenient and rapid method for evaluating the proportion of dolomite end-member in minerals of the dolomite-ankerite series, and for estimating the amount of admixed calcite.

1028 FORBES, S., BOUND, G. P. and WEST, T. S. The determination of selenium in soil and plants by differential pulse cathodic-stripping voltammetry. *Talanta.* 1979, **26**, 473-477.
A method is described for the determination of selenium by differential pulse cathodic stripping voltammetry (DPCSV) at a hanging mercury drop electrode (HMDE). The dried sample is burnt in an oxygen flask and the selenium absorbed into a persulphate-sulphuric acid mixture. The solution is analysed by DPCSV following treatment with hydrochloric acid to destroy excess persulphate and to reduce the Se VI to Se IV. Results are given for two soils and a series of plant materials and compared with those obtained by fluorimetric analysis of the piazselenol complex.

995 GOODMAN, B. A. An investigation by Mössbauer and electron paramagnetic resonance spectroscopy of the possible presence of iron-rich impurity phases in some montmorillonites. *Clay Miner.* 1978, **13**, 351-356.
Some montmorillonites with low iron content have been investigated by Mössbauer and EPR spectroscopy. EPR results indicate that, in addition to structural Fe^{3+}, a phase with interacting Fe^{3+} ions is also present. Mössbauer results show that, if this phase is an oxide or hydroxide impurity, its particle volume must be $<< 10^4 Å^3$. It is concluded that the iron-rich phase consists of very small particles associated with surface sites in the minerals.

982 GOODMAN, B. A. The Mössbauer spectra of nontronites: consideration of an alternative assignment. *Clays Clay Minerals.* 1978, **26**, 176-177.
An alternative assignment of the Mössbauer spectra of nontronites, which does not require the presence of more than one phase, is considered with reference to new and previously published results.

1010 GOODMAN, B. A. and BAIN, D. C. Mössbauer spectra of chlorites and their decomposition products. *International Clay Conf., 1978.* Edited by M. M. Mortland and V. C. Farmer. Amsterdam, Elsevier, 1979, 65-74.
Examination of several chlorites by Mössbauer spectroscopy has shown that at least half of the iron is in the ferrous form with a principal component that has similar parameters to that from the site with *cis* OH groups in biotite. Some specimens contained ferric iron in sites with tetrahedral coordination in addition to that in the octahedral sites which was more generally observed. Heating to the major endotherm followed by treatment with HCl resulted in partial conversion to vermiculite in the low-iron specimens and this was accompanied by complete oxidation of the iron. With iron-rich specimens there was no tendency to form vermiculites and oxidation of the iron was incomplete, although there was some disruption of the lattice.

1030 GOODMAN, B. A. and CHESHIRE, M. V. A Mössbauer spectroscopic study of the effect of pH on the reaction between iron and humic acid in aqueous media. *J. Soil Sci.* 1979, **30**, 85-91.

Mössbauer spectroscopy has been used to study the effect of pH on the reaction of iron with humic acid. At pH values above 3 the iron was found in the ferric form. On lowering the pH reduction occurred, with the ferrous species going into solution, partly as the free ion and partly as organic complexes. Raising the pH led to reoxidation and precipitation of the iron in an inorganic form.

GOODMAN, B. A. and LINEHAN, D. J. An electron paramagnetic resonance study of the uptake of Mn (II) and Cu (II) by wheat roots. In: *The Soil-Root Interface.* Editors: J. L. Harley and R. Scott Russell. London, Academic Press, 1979, 67-82.

The mechanisms involved in the uptake of micronutrient cations are far from fully characterized. Certain micronutrients have unpaired electrons making electron paramagnetic resonance (EPR) spectroscopy a potentially useful techniquq in the study of their uptake. Manganese and copper were chosen for preliminary experiments and methods devised for the EPR study of living roots. Whilst little progress was possible with manganese, copper uptake was shown to involve an initial immobilization with the subsequent progressive appearance of a soluble complex having EPR parameters similar to those of some copper-amino acid complexes.

GOODMAN, B. A., LINEHAN, D. J. and POWELL, H. K. J. An electron paramagnetic resonance study of the uptake of copper (II) by wheat roots. *Proc. 2nd N.Z. Seminar on Trace Elements and Health.* Editors: J. Aggett, T. Kjellstrom and D. Crowe. Auckland, University of Auckland, 1979, 63-70.

The mechanisms involved in the uptake of micronutrient cations by plant roots are far from fully characterized. In many cases there is no direct relationship between the total amount present in the soil and that fraction which can be taken up by the plant. For those elements, such as copper, which have unpaired electrons, electron paramagnetic resonance spectroscopy (EPR) is a valuable method in the study of their uptake. Using EPR it has been shown that during a 30 min. period of uptake by wheat roots, copper (II) is immobilized within the roots or possibly upon their surfaces. Subsequently a soluable copper (II) complex appears having EPR parameters consistent with those of copper-amino acid complexes. For roots in a moist atmosphere, a condition frequently occurring with plants growing in soils, these complexes accumulate within freespace of the root. A computer model has been set up to calculate the possible distribution of copper (II) amongst the competing amino acids present in these roots. Ternary complexes have been shown to play a dominant role with asparagine, histidine and alanine being the most important ligands.

984 GUZEL, N. and WILSON, M. J. Release of potassium by acid extraction in relation to the mineralogy of selected soils from Southern Turkey. *Agrochimica.* 1978, **22**, 48-60.

The non-exchangeable potassium of four profiles representative of widely occurring soil series in the Cukurova Plain of the Seyhan region of Southern Turkey has been investigated by making successive 1.ON HC 1 extractions on total soils and on the clay, silt and sand separates. In general, the clay fractions contain a major part of this form of potassium where it is associated mainly with a montmorillonitic mineral containing interstratified mica layers. Mica existing as a separate phase releases its potassium less readily. Mineralogical examination provided a basis for the interpretation of the general variation in total, non-exchangeable and exchangeable forms of potassium, both within and between the soils.

1074 HARGREAVES, M., KING, A. F., NORRIS, J. D., SANZ-MEDEL, A. and WEST, T. S. Non-dispersive atomic fluorescence spectrometry with a carbon filament atom reservoir. *Anal. Chim. Acta.* 1979, **104**, 85-92.

The non-dispersive determination of Bi, Cd, Hg, Te, Tl and Zn on a carbon filament atomizer with electrodeless discharge lamps and inverse cassegranian optics is described. The non-dispersive system shows distinct advantages for elements such as Te whose principal fluorescence lines fall within the range of the solar-blind photomultiplier-detector, marginal advantages for Cd, Hg and Zn where only one line lies in the range. It is inferior to the dispersion technique for elements such as Bi, Pb and Tl whose lines lie at the extremes of the detector's useful range.

HOWAT, D., McCOMBIE, C. M., McGREGOR, A. J. (W. of Scotland Agric. Coll.) and SHIPLEY, B. M. Drainage of soils of low permeability: the Slamannan Project. *West of Scotland Agricultural College Res. & Development Publ. No. 8, 1978.*

The soils of the experimental sites are described with reference to the significance of some of their physical properties which affect drainage.

1037 HULME, P. D. *Calliergon richardsonii* (Mitt) Kindb from the late-Devensian of Lang Lochs mire, Shetland. *J. Bryol.* 1979, **10**, 281-285.

Macrofossils of *Calliergon richardsonii*, a moss not found in the living state in Britain, have been identified in mineral inwash deposits from Mainland Shetland. Associated macrofossils and pollen indicate a late-Devensian origin and correlation of pollen spectra with those of a similar ^{14}C-dated site in Shetland suggest a date around 10,400 years ago.

HULME, P. D. Peatland classification with special reference to Scotland. *Proc. Int. Symp on Classification of Peat and Peatlands, Hyytiala, Finland.* 1979, 76-81.

The feasibility of classifying peatlands using a system based on concepts introduced by Radforth, for Canadian peatlands, has been assessed in two selected areas in Scotland. Its success as a general classification suggests that it may have a wide application and provide the basis for detailed local and user-orientated systems incorporating features such as vegetation, hydrology and morphology.

988 JONES, D. Surface morphology of narcissus flowering stems as revealed by scanning electron microscopy. *Micron,* 1978, 9, 95-97.

Surface features of biological tissue examined in a scanning electron microscope can vary according to the preparative technique used to preserve and dry the material. This paper reports the finding of wax in the form of irregularly-shaped protrusions on free-dried flowering stems of narcissus whether or not they had been preserved chemically. This wax was not present on critical-point dried stems similarly treated.

JONES, D. and WILSON, M. J. Lichen fungi and weathering of minerals: an electron microscope and x-ray micro-analysis study. *Proc. R. Microsc. Soc.* 1979, **14**, 226.

As an exploratory investigation, features of weathered minerals in a lichen-encrusted basalt, which is a calcium-rich rock, have been studied in a scanning electron microscope. Evidence was obtained to show that the fungal component of the lichen was instrumental in the degradation of the calcium-containing minerals.

1038 KHALIGIE, J., URE, A. M. and WEST, T. S. An investigation of atom collection phenomena in atomic absorption spectrometry of copper. *Anal. Chim. Acta.* 1979, **107**, 191-200.

An atom trapping device has been used to collect and subsequently release species for measurement by atomic absorption spectroscopy in air-acetylene flames. The behaviour of copper has been examined. A sensitivity value corresponding to 6 x 10^{-4} ppm was obtained following 10 minutes collection. This is *ca.* two orders of magnitude more sensitive than the normal technique of atomic absorption measurement. The presence of a thousand fold amount of aluminium enhanced the signal strength.

1023 LINEHAN, D. J. Humic acid and iron uptake by plants. *Pl. Soil*. 1978, **50**, 663-670.

Humic acid readily forms complexes with iron and it has been suggested that humic acid may increase plant growth by providing a soluble source or iron, thus preventing iron deficiency. However, it has now been shown that humic acid, when added to nutrient solutions containing ferric EDTA or ferric citrate, depresses the uptake of iron by wheat roots. The way in which humic acid influences iron uptake depends on the nature of the iron species already present in solution.

990 LINEHAN, D. J. Polycarboxylic acids extracted by water and by alkali from agricultural top soils of different drainage status. *J. Soil Sci.* 1978, **29**, 373-377.

Humic substances present in solution in soils may be taken up by plants and alter their growth and metabolism. Such soluble humic substances have been isolated from soils having varying degrees of drainage impedance. The amounts were much higher in very poorly-drained soils with, in one Soil Association, a ten-fold difference between the well-drained and poorly-drained sites. In contrast, the proportion of total organic matter accounted for by the structurally similar polycarboxylic acid of fulvic acid was lower in the very poorly-drained soils. The amount of oxalate-extractable aluminium, thought to be involved in absorbing these soluble polycarboxylic acids, decreases with increasing drainage impedance. Since soluble humic substances may influence plant growth under field conditions the factors influencing their amounts are being further investigated.

1022 LINEHAN, D. J. The uptake by plants of polymaleic acid: a polycarboxylic acid structurally related to those of soils. Pl. Soil, 1978, **50**, 625-632.

Investigations of the physiological effects of soil humic substances are complicated by uncertainty regarding their uptake by plants. It has been shown, however, that polymaleic acid is absorbed by wheat and tomato plants and that a significant proportion is translocated from the roots to the shoots. Since this acid is known to be similar to the humic substances in the soil solution, this provides evidence that these are similarly absorbed and thus could have direct effects on plant growth.

1051 LINEHAN, D. J. and SHEPHERD, H. A comparative study of the effects of natural and synthetic ligands on iron uptake by plants. *Pl. Soil*, 1979, **52**, 281-289.

The humic substances of soil solutions are soluble low molecular weight polycarboxylates structurally related to fulvates. They are thought to influence the availability to plants or iron and other micro-nutrients. Although humic acid, which does not appear in soluble forms in Scottish soils, has been widely investigated in this respect, the soluble polycarboxylates hitherto have not. It has now been shown that they influence the uptake of iron by plants rather differently from humic acid which enhances uptake to the shoots only over a rather narrow concentration range. Fulvate, water-extractable soil polycarboxylate and the, structurally similar, synthetic polymer polymaleic acid, are effective in enhancing uptake to shoots over a much wider concentration range.

1024 MACDONALD, I. R. and GORDON, D. C. The effect of chlorflurenol on geosensitivity and light inhibition of cress roots. *J. Exper. Bot.*, 1979, **30**, 65-70.

The growth of roots of some species is contorted by light. This report showing that chlorflurenol, a compound which interferes with the ability of a plant to respond to gravity, induces straight growth, provides evidence for the view that light distorts root growth by increasing the geo-sensitivity of the root.

1006 MACDONALD, I. R. and GORDON, D. C. An inhibitory effect of excess moisture on the early development of *Sinapis Alba* L. seedlings. *Plant, Cell Environment*, 1978, **1**, 313-316.

Because of its regulating effect on oxygen diffusion, mustard seedlings in the early stages of growth are very sensitive to the presence of excess moisture. A moisture suction of at least 3 cm water is necessary for optimal development for seedlings grown on a plane. Water, at a suction of less than 3 cm water, slows down the growth of the radicle, and cotyledonary pigment synthesis, due to a restricted flow of oxygen through the mucilaginous seed coat. However, the equivalent oxygen barrier effect would be encountered in the field only in exceptionally wet conditions.

1004 MACDONALD, I. R. and GORDON, N. D. C. The regulation of root growth in cress seedlings by light and gravity. *J. Exper. Bot.*, 1978, **29**, 1051-1058.

A critical phase in the growth of a seedling is the early orientation of the emerging radicle. Survival depends on the root growing downwards, but the mechanisms by which a plant utilises gravity in root growth is still obscure. This study explores the interaction between light and gravity in the regulation of root growth.

1054 McHARDY, W. J. Application of scanning electron microscopy and microanalysis to the study of soil mineralogy. *Geol. Appl. Idrogeol.*, 1977, **12**, 213-233.

The principles of scanning electron microscopy and microanalysis are described together with specimen preparation techniques. Several special applications to the study of kaolinization processes, surface features of sand grains, deep sea chart and interparticle relationships in soil texture are reviewed. Examples of work done at the Macaulay Institute on soil micromorphology, manganese accumulations and the weathering of biotite are described.

1009 MACKENZIE, R. C. Clay mineralogy — whence and wither? *International Clay Conf., 1978*. Edited by M. M. Mortland and V. C. Farmer. Amsterdam, Elsevier, 1979, 1-14.

While it is almost impossible to define *clay* in words, it is easy to recognise it in practice — as has in fact been appreciated from prehistoric times. Very early distinctions between clays (or earths) were based on superficial features and uses, and nomenclature could be confusing because of lack of appreciation of diversity and synonymy. Although much knowledge on clays and their uses had accrued by the mid-sixteenth century it was towards the end of the eighteenth century before clay minerals, as distinct from clays, came to be recognised and distinguished chemically. Only during the present century has it been possible to characterize species adequately and at present a large number of investigational techniques are required in clay studies. In the near future interest in surface characteristics and chemistry and in the formation and properties of organomineral compound is likely to be strongly maintained or even increased: both these aspects are of great importance in soil science.

MACKENZIE, R. C. Some aspects from the history of thermal analysis. *Zborn. VIII Celostat. Konf. term. Analyze*, 1979, 353-356.

A brief review. Among the highlights are: 315 BC — the first record of the use of heat for distinguishing minerals (Theophrastus); 27 BC — the first record of loss of weight on heating (Vitruvius); *ca* 1630 — the first thermostat (Drebbel); 1737, 1782 — the first EGD and EGA experiments (Hales and Wedgwood); 1790 — the first ice calorimeter (Lavoisier and De La Place); 1877 — the first mass-change determinations (Harnay and Ramsay); 1883 — the first heating curve for phase analysis (Le Chatelier); 1895 — the first electric-resistance, wire-wound, tube furnace (Charpy); 1899 — the first DTA (Roberts-Austen). Developments in the present century include the introduction of the first commercial instruments for TG (Chevenard, 1936) and for DTA (Eberbach, 1949).

1041 MALCOLM, R. E. and VAUGHAN, D. Comparative effects of soil organic matter fractions on phosphatase activities in wheat roots. *Pl. Soil*, 1979, **51**, 117-126.
Soil organic matter is a complex mixture derived from plant and animal remains, the micro-flora and fauna, and various exudates secreted by living matter. Most chemical fraction techniques will thus produce an arbitrary mixture of substances. In this investigation most soil organic matter fractions prepared using several fractionations inhibited phosphatase activity in wheat roots, but to different extents. Humic acid and fractions obtained from it by boiling with water were more inhibitory than the other soil fractions, but there was no clear connexion between the biological activity of soil organic matter and its chemical composition.

1002 MALCOLM, R. E. and VAUGHAN, D. Effects of humic acid fractions on invertase activities in plant tissues. *Soil Biol. Biochem.*, 1979, **11**, 65-72.
Changes in invertase activity are closely correlated with changes in plant growth. Soil organic matter fractions have a differential effect on the invertase activity of a given plant and these effects which are usually inhibitory, very between plant species. It is suggested that the inhibitory effects are due to the soil organic matter combining with the invertase, but not at the enzyme site which is necessary for the formation of the enzyme-substrate complex.

1036 MALCOLM, R. E. and VAUGHAN, D. Humic substances and phosphatase activities in plant tissues. *Soil Biol. Biochem.*, 1979, **11**, 253-259.
Phosphorus plays an essential role in plant metabolism and subsequent growth, but little is known about the effects of soil organic matter components on those enzymes concerned with the biochemistry of phosphates in higher plants. It has now been shown that humic acid and fractions obtained from it by water or acid boiling will reduce phosphatase activities in the tissues of roots of several crops of agricultural importance. On the other hand, phenolic acids which are found in the soil solution and readily taken up by the plant roots have no effect on phosphatase activity. Work is now continuing to establish the significance of these observations in relation to the plant growth response.

1026 MILLER, H. G., COOPER, J. M., MILLER, J. D., and PAULINE, O. J. L. Nutrient cycles in pine; and their adaptation to poor soils. *Can. J. For. Res.*, 1979, **9**, 19-26.
Fluxes of nitrogen, phosphorus, potassium, calcium and magnesium through the tree-soil system are presented, based on models derived for nitrogen-fertilized Corsical pine. The development of nitrogen deficiency, and the significance of nitrogen remobilised from older tree tissues, are discussed. Models of nutrient flux at optimum growth illustrate the mechanisms evolved by trees to cope with soils of low nutrient status. Once nutrient cycles have become established the trees seem to demand very little additional potassium and magnesium from the mineral soil horizons, but there remains a continuing requirement for additional soil nitrogen, phosphorus and calcium.

MILLER, H. G. and MILLER, J. D. Sulphur content and acidity of rainwater at six rural sites across Scotland. *Proc. Sulphur Emissions and the Environment, London, 1979.* London, Soc. Chem. Ind., Water and Environm. Group, 1979, 77-80.

MILLER, H. G., MILLER, J. D. and COOPER, J. M. Changes in sulphur content and acidity of rainwater on passing through the canopy of sitka spruce forests. *Proc. Sulphur Emissions and the Environment, London, 1979.* London, Soc. Chem. Ind., Water and Environm. Group, 1979, 225-227.
Rainwater passing through the canopy of 30-year-old *picea sitchensis* on the east coast of Scotland showed an increase in most major nutrient cations, a similar increase in sulphate, no change in nitrate and a marked decrease in acidity. From comparison with the changes found in water collected beneath an inert trapping surface of polyethylene-coated wire mesh, it is concluded that in addition to an input of sulphur of 20 kg ha^{-1} yr^{-1} in rainwater there is a further input of 4 kg sulphur in gases and particles filtered from the atmosphere by the tree surfaces.

MILLER, H. G. and ROBERTSON, R. A. Peatland forestry in Scotland. In: *Profitable use of our land resources,* Edited by N. Tomter. Scottish Peat and Land Development Association, 1979, 44-47.

This paper presents a brief review of the development of peatland forestry in Scotland, including species selection, cultivation, drainage and use of fertilizers. As most of the difficulties of establishment have now been overcome, more attention is being directed to the problem of harvesting and restocking.

MORRISON, A. R. and SHARP, B. L. A microprocessor controlled laser remote sensing system. *Proc. Anal. Div. Chem. Soc.*

An instrumental system for the determination of sulphur dioxide in agricultural environments is described. The system uses the differential LIDAR (Light Detection and Ranging) technique employing a tunable dye laser transmitter and telescope receiver. The principles of the LIDAR technique and its advantages over conventional methods are discussed.

MORTLAND, M. M. and FARMER, V. C., *eds.* International Clay Conference, 1978. Amsterdam, Elsevier, 1979.

1035 O'BRIEN, R. M. G. (Grampian Region), ROMANS, J. C. C. and ROBERTSON, L. Three soil profiles from Elephant Island. *Br. Antarct. Surv. Bull.*, 1979, No. 47, 1-12.

Three soil profiles from ice-free areas around the periphery of Elephant Island are described and discussed. All three sites are underlain by continuous permafrost and the time interval since exposure to subaerial weathering and leaching is believed to range from several hundred years to about 10,000 years. Incipient profile horizon differentiation is just detectable at the oldest site, but all three profiles show very little evidence of mineral weathering.

997 PATERSON, E. and MITCHELL, B. D. Erosion deposits in tile-bound soils. *Agric. Water Management*, 1978, **1**, 311-317.

The mechanism of silting up of tile field drains has been examined by comparing the physical and mineralogical characteristics of deposits in drains with those of the clay soil directly above. The deposits consist of clay, silt and sand and are distinctly laminated. They appear to be the result of internal erosion of the soil. The processes operative seem to have been: (a) inflow of soil through the drain joints; (b) sedimentation in the drain; (c) elution of very fine material.

1017 PIDGEON, J. D. and RAGG, J. M. Soil, climatic and management options for the direct drilling cereals in Scotland. *Outlook in Agric. (Special Issue)*, 1979, **10**, 49-55.

Direct drilling of cereals has made little impact in Scotland. A review of soil and climatic limitations suggests that with appropriate management a large proportion of the Scottish cereals area is potentially suitable for direct drilling if the motivation arises. Management of uncultivated soils and possible future developments in zero tillage for cereals are discussed.

983 RAGG, J. M., BRACEWELL, J. M., LOGAN, J. and ROBERTSON, L. Some characteristics of the brown forest soils of Scotland. *J. Soil Sci.*, 1978, **29**, 258-262.

The term brown forest soil, which has been used in Europe for almost seventy years, embraces a range of soils too wide for classification purposes. Eighty-six Scottish brown forest soil profiles have been divided into two groups, podzolic and non-podzolic, on the basis of various morphological and physical properties. Statistical analysis of analytical data and environmental properties have revealed differences between these groups, altitude, accumulated temperature, base status, pyrolysis ratio, C/N ratio and pyrophosphate-to dithionite-extractable iron ratio being the most significant variables. Of these the pyro-phosphate-to dithionite-extractable iron is a more useful group discriminator than the widely accepted extractable sesquioxide to clay content ratio.

1014 REAVES, G. A. and BERROW, M. L. The lead content of the soils of the Wigtownshire area of Scotland. *J. Sci. Fd. Agric.*, 1979, **30**, 1-7.

In an investigation into the levels of total and extractable lead in the soils of Wigtownshire highly significant correlations were found between total lead and soil depth, loss-on-ignition and extractable lead. The chief feature of the relationships between total lead, depth and loss-on-ignition was the lead enrichment of surface horizons which was almost always most intense when the surface horizon was organic. The relationship between total and extractable lead held for a wide range of soil texture and drainage class. No significant correlation was found between the ratio of extractable to total lead and sampling depth, loss-on-ignition or drainage class.

REITH, J. W. S., BERROW, M. L. and BURRIDGE, J. C. Effects of copper in distillery wastes on soils and plants. *Proc. Int. Conf. Management and Control of Heavy Metals in the Environment, London, 1979.* 1979, 537-540.

Pot ale, a liquid waste from the production of malt whisky, contains appreciable amounts of copper and has been applied to some fields for over 70 years. Analyses of surface soil and of horizons from profile pits in fields used as disposal sites have shown that most, perhaps all, of the applied copper has been retained in the top 20 to 30 cm of soil. The EDTA-extractable copper levels range from about 5 to 300 mg per kg soil and are substantially more than 50 per cent of the total copper in the soil. Plant samples from two sites with exceptionally high levels had copper contents between 7 and 26 mg per kg dry matter, only clover, potato haulms and turnip shaws containing more than 20 mg Cu. Only in the case of rape did crop growth appear to be restricted by the high copper content in the soil.

REITH, J. W. S., BURRIDGE, J. C. and BERROW, M. L. Effects of NPK fertilizers on trace element uptake by herbage. *J. Sci. Fd. Agric.*, 1979, **30**, 743.

ROBERTSON, R. A. and STOVE, G. C. Application of remote sensing to peat survey. In: *Profitable use of our land resources.* Edited by N. Tomter. Scottish Peat and Land Development Association, 1979, 48-49.

A research project designed to develop the potential of remote sensing, including satellite imagery, for peat survey and evaluation is outlined and discussed.

1044 RUSSELL, J. D. An infrared spectroscopic study of the interaction of nontronite and ferruginous montmorillonites with alkali metal hydroxides. *Clay Miner*, 1979, **14**, 127-137.

To gain an insight into the reactions that might occur when soils are treated with alkali metal hydroxides to improve soil stability, infrared spectroscopy has been used to investigate the interaction of LiOH, NaOH, KOH and CsOH with a range of clay minerals of the dioctahedral smectite group. It has been shown that these hydroxides deprotonate structural hydroxyl groups that are co-ordinated to octahedral Fe^{3+} in minerals such as montmorillonite and nontronite. Marked changes in wavenumber of Si-O vibrations indicate that the silicate framework becomes distorted, and this is confirmed by X-ray diffraction and Mössbauer spectroscopy which show respectively a larger unit cell *b* dimension and a more unsymmetrical electrical field in the vicinity of Fe^{3+} ions in the octahedral layer of these minerals. These changes are only partially reversible.

1043 RUSSELL, J. D. Infrared spectroscopy of ferryhidrite: evidence for the presence of structural hydroxyl groups. *Clay Miner,* 1979, 14, 109-114.
Ferrihydrite, recently identified as a naturally occurring hydrated iron oxide with a defect-hematite structure, is probably of fairly widespread occurrence in soils and sediments. The structure is shown here to be

incorrect, infrared spectroscopy providing unambiguous evidence for the presence of OH groups in the mineral and at its surface, and giving an estimate of their amount. To take account of these groups, a new formula — $Fe_2O_3.2FeOOH.2{\cdot}6H_2O$ — is proposed. The ready accessibility of the OH groups in exchange reaction is potentially important in soil-fertilizer interactions, but in order that these interactions be understood, the structure of this poorly crystalline mineral must be re-appraised.

985 RUSSELL, J. D. and RUSSELL, D. R. The effect of Fe-for-Si substitution on the *b*-dimension of nontronite. Clay Miner, 1978, **13**, 133-137.

Study by x-ray diffraction of a series of chemically analysed dioctahedral nontronites has shown that their 060 spacings are large and fall in an area generally assigned to trioctahedral minerals. It is proposed that the large values are due to appreciable iron-for-silicon substitution in tetrahedral sheets causing an increase in *b*-dimension. Factors which take account of this type of substitution in dioctahedral smectites have been calculated from the x-ray and compositional data and incorporated into existing formulae for calculating *b* from composition. These formulae are usually less successful in predicting *b*, however, than a proposed new one in which *b* is determined from ferric iron content only.

1021 RUSSELL, J. D., GOODMAN, B. A. and FRASER, A. R. Infrared and Mössbauer studies of reduced nontronites. *Clay Minerals,* 1979, **27**, 63-71.

Infrared and Mössbauer spectroscopy have shown that structural iron in nontronites is reduced by hydrazine and dithionite, the extent of the reduction with the latter reagent depending on the composition of the nontronite. Hydrazine causes only minor reduction of all the nontronite studies, but dithionite extensively reduces those that contain tetrahedrally co-ordinated iron by dissolving this iron and then reducing that in octahedral co-ordination. Small amounts of glauconite- or celadonite-like minerals are formed during this extensive reduction which is accompanied by the formation of intense blue-green colours in the nontronite. The development of these colours, which are similar to those observed in water-logged soils, suggests the reduction mechanisms described may operate in poorly drained soils that contain ferruginous smectite.

998 RUSSELL, J. D., FARMER, V. C. and LEWIS, D. G. (Waite Agric. Res. Inst., Australia.) Lattice vibrations of boehmite (γ-AlOOH): evidence for a C_{2v}^{12} rather than a D space group. *Spectrochim. Acta.*, 1978, **34A**, 1151-1153.

To assist the recognition of infrared absorption bands associated with the surface of boehmite crystals, an analysis of the absorption spectrum arising from bulk vibrations has been made.

1072 SCOTT, N. M. Effect of sulphur in rain on the growth and sulphur response of oats in pot cultures. *J. Agric. Sci.*, 1979, 93, 765-767.

The effect of sulphur in rain on the yield and sulphur content of oats has been measured by comparing pot cultures grown in two environments, one with access to both gaseous atmospheric sulphur and rain sulphur, and the other to gaseous sulphur only. The results showed the importance of atmospheric sulphur to crops, particularly that in rain, and the desirability of ensuring a soil sulphur content in excess of 10 ppm phosphate-extractable sulphate.

1008 SCOTT, N. M. and MUNRO, J. The sulphate status of soils from north Scotland. *J. Sci. Fd. Agric.*, 1979, **30**, 15-20.

In a survey of soils from 125 farms in north Scotland, 46% had calcium phosphate extractable sulphate values below 13 mg S/kg soil and so may require additional sulphur to produce optimum yields. Using five of the soils, a pot experiment with ryegrass showed a response to added sulphur in yield and uptake in both harvests. Sulphur deficiency symptoms were evident in the ryegrass from some of the nil sulphur pots in the second harvest.

1067 SINCLAIR, A. H. Availability of potassium to ryegrass from Scottish soils. 1. Effects of intensive cropping on potassium parameters. *J. Soil Sci.*, 1979, **30**, 757-773.

Potassium supply from soil to crop depends on the ability of soils to release potassium reserves that are not immediately available to plants. The amounts of these reserves were determined for soils from five contrasting series by exhaustive cropping of ryegrass in pots, and were at least as great as the immediately-available potassium. Uptake of K correlated well over the entire cropping period with the immediately-available potassium. Drying- and-wetting fresh soil samples severely depleted of plant-available potassium raised their potassium status. The increases amounted to about ¼ of the potassium removed during the cropping cycle, and were greater for soils of lower potassium status. Freezing-and-thawing did not affect the potassium status of these soils.

1066 SINCLAIR, A. H. Availability of potassium to ryegrass from Scottish soils. 11. Uptake of initially non-exchangeable potassium. *J. Soil Sci.*, 1979, **30**, 775-783.

The rate of release of non-exchangeable potassium from soils is important for long-term potassium supply to crops. Measurements of soil solution potassium, combined with cumulative potassium uptake by ryegrass in pots, from 10 Scottish soils, showed that there are two categories of non-exchangeable potassium with markedly different rates of release, having diffusion coefficients of 10^{-7} and 10^{-15} $-10^{-16}cm^2s^{-1}$ respectively. The slower-released category comes from the internal surfaces of micaceous clays, and provides a long-term reserve of potassium from which the readily available sources can be replenished. This category depended on soil series, the ability of the series to release it following the descending order: Strichen>Caprington>Countesswells>Insch>Foudland.

980 SOONG, R. and FARMER, V. C. The identification of sulphide minerals by infrared spectroscopy. *Mineral Mag.*, 1978, **42**, M17-20.

The value of infrared spectra in identifying sulphide minerals has been assessed by surveying the spectra of some forty specimens. Except for minerals whose metallic conductivity obliterates vibrational features, the spectra permit rapid recognition of sulphide minerals either alone or in mixtures. Spectra of 25 pure or nearly pure specimens are presented. The iron sulphides can form in soils under anaerobic conditions, and others can give rise to heavy metal toxicities in the neighbourhood of sulphide outcrops.

1032 SPARLING, G. P. and CHESHIRE, M. V. Effects of soil drying and storage of subsequent microbial growth. *Soil Biol. Biochem.*, 1979, **11**, 317-319.

Yeast numbers were much higher and the numbers of bacteria and fungi lower when air-dried soils were remoistened and incubated with 1% glucose, than in similar incubations with fresh soils. The effect became more marked with decreasing soil pH, and at low (5°) temperature. As many yeasts synthesize xylose, these results explain the high levels of sugar synthesized during previous incubations of pre-dried soils.

STOVE, G. C. and ROBERTSON, R. A. Improving our image. In: *The High Frontier*. Edited by B. Low. Glasgow, The Third Eye Centre Ltd., 1979, 11-12, 30.

The application of methodology developed for peat resource survey has illustrated the usefulness of multi-level and multi-band aerial photography in classifying LANDSAT multispectral imagery. Ground truthing to characterise the thematic maps plotted from the aerial photography and LANDSAT imagery was based primarily on vegetation surveys. The results of this work are illustrated with a series of maps and photographs and the usefulness of the approach is assessed.

1069 STOVE, G. C. and ROBERTSON, R. A. Remote sensing in peat-resource and land-use survey. *A.R.C. Research Review*, 1979, **5**, 21-27.

To accelerate peat-resource, vegetation and land-use surveys in remote areas of Scotland, a research programme on the applications of remote sensing is progressing in three inter-related fields, namely (1) acquisition of imagery, (2) image analysis and (3) photogrammetric mapping. Different types and scales of imagery are evaluated and applied in the classification of satellite multispectral scenes from the LANDSAT space programme and an automated photogrammetric mapping system is described. Classification of a LANDSAT scene of Lewis for peat resource mapping, has shown that a photogrammetric approach based on aerial survey techniques together with an efficient multi-stage sampling strategy is central to the entire monitoring and classification procedure.

981 TAIT, J. M., YOSHINAGA, N. (Ehime Univ., Japan) and MITCHELL, B. D. The occurrence of imogolite in some Scottish soils. *Soil Sci. Pl. Nutr.*, 1978, **24**, 145-151.

Imogolite, a hydrous aluminium silicate mineral, occurs in small amounts in the B horizon of several freely drained Scottish soils. Its occurrence may be of value in assessing soil-forming processes.

1011 TEJEDOR-TEJEDOR, M. I. (Univ. Madrid, Spain) and PATERSON, E. Reversibility of lattice collapse in synthetic buserite. In: *International Clay Conf., 1978*. Edited by M. M. Mortland and V. C. Farmer, Amsterdam, Elsevier, 1979, 501-508.

The ability of hydrous oxides of manganese to sorb large amounts of certain cations is well known, but the mechanisms by which this occurs is more obscure. One of the main difficulties is a lack of knowledge of the structure of the birnessite group, of which buserite may be considered the parent compound. In this study the structural changes occurring on sorption of various cations have been studied using x-ray diffraction. The information gained in this way should prove to be of value in the assessment of the behaviour of agriculturally important micronutrients such as cobalt.

991 URE, A. M. and BACON, J. R. Comprehensive analysis of soils and rocks by spark source mass spectrometry. *Analyst*, 1978, **103**, 807-822.

A description is given of the technique used for the quantitative analysis of rocks and soils by spark source mass spectrometry with aluminium as the conducting material. Details are given of photographic plate emulsion calibration and evaluation methods together with the interference correction procedures essential before measuring, and finally applying, the relative sensitivity coefficients used to standardize the analyses. Over fifty elements can be determined and a typical precision of $\pm$ 10-15% is attained. The techniques are illustrated by application to the analysis of soils, concentrates of acetic acid extracts of soils, and U.S. Geological Survey Standard Rocks G-2 and AGV-1.

978 URE, A. M. and BACON, J. R. Scandium, yttrium and the rare earth contents of water lily (nuphar lutea). *Geochim. Cosmochim. Acta.*, 1978, **42**, 651-652.

The contents of scandium, yttrium and the rare earth elements, determined by spark source mass spectrometry, for water lily *(Nuphar lutea)* from Dow Loch (Scotland) have been compared with those for the National Bureau of Standards Orchard Leaf SRM 1571 and Dow Loch sediment. In contrast to the conclusions from a recent North American study of aquatic plants no evidence of accumulation of any of these elements has been found.

1019 URE, A. M., BACON, J. R., BERROW, M. L. and WATT, J. J. The total trace element content of some Scottish soils by spark source mass spectrometry. *Geoderma*, 1979, **22**, 1-23.

Quantitative methods of analysis by spark source mass spectrometry have been used to determine the total trace element content of the surface horizons of 10 Scottish arable soils derived from parent materials of different geological origin and used for earlier trace element surveys. Other methods have been used to supplement these analyses for 12 elements including the major elements, and results for the total of 62 elements in the 10 soils are reported. The results are discussed in terms of the geological nature of the soil parent material making use of 62-element soil fingerprints for visual comparison.

VAUGHAN, D. Soil organic matter and root surface enzymes. In: *The Soil-Root Interface*. Editors: J. L. Harley and R. Scott Russell. London, Academic Press, 1979, 439-440.

Humic and fulvic acids inhibit invertase activity on the root surface of winter wheat, but humic acid is more effective than fulvic acid. Experiments using (^{14}C) — labelled soil organic matter showed that humic and fulvic acids are absorbed onto the root surface but there is no connection between the amount of ^{14}C absorbed and the effect of these fractions on invertase activity. These observations add weight to the current view that soil organic matter fractions can influence plant metabolism directly.

1055 VAUGHAN, D and JONES, D. Effects of Dazomet on phenolase activity in sclerotia of *Sclerotinia Sclerotiorum*. *J. Exper. Bot.*, 1979, **30**, 751-758.

The plant pathogenic fungus *Sclerotinia Sclerotiorum* survives in the soil as sclerotia which are enveloped in a black rind. The enzyme phenolase, which is found in the sclerotial exudate, is thought to be implicated in the synthesis of the black pigment in the cell walls of this rind. The phenolase was shown to be inhibited by Dazomet, a commercially used soil fumigant, the inhibition being due to the complexing of copper which is an element vital for the activity of this enzyme.

1034 VAUGHAN, D. and MALCOLM, R. E. Effects of acid on invertase synthesis in roots of higher plants. *Soil Biol. Biochem.*, 1979, **11**, 247-252.

Humic acid stimulates cell elongation and the development of invertase activity in plant roots, but does not affect net protein synthesis generally. Using "specific inhibitors" of protein and nucleic acid synthesis it has now been shown that the stimulation of invertase activity is due to an effect of humic acid on the synthesis of the enzyme. Humic acid also affects ribonucleic acid synthesis and it is suggested that this soil organic matter influences the synthesis of specific plant proteins by an effect on the nucleic acids.

1003 VAUGHAN, D. and MALCOLM, R. E. Effect of soil organic matter on peroxidase activity in wheat roots. *Soil Biol. Biochem.*, 1979, **11**, 57-63.

Soil organic matter fractions inhibited peroxidase activity in wheat roots. Humic acids were more effective than fulvic acids, while some phenolic acids, which are found in soil solutions, were also inhibitory. Because increases in peroxidase activities in plant cells are usually closely associated with the cessation of cell elongation, the inhibitory effects of some soil organic matter components on the activity of this enzyme may be one factor contributing to their enhancing plant growth.

1015 VAUGHAN, D., ORD, B. G. and MALCOLM, R. E. Effect of soil organic matter on some root surface enzymes and uptakes into winter wheat. *J. Exper. Bot.*, 1978, **29**, 1337-1344.

Soil organic matter inhibits the activity of root invertase and the uptake of carbonhydrates into the root. It also inhibits the activity of root phosphatase, but stimulates the uptake of inorganic phosphate. These observations demonstrate that soil organic matter affects the activity of root enzymes, adding weight to the current view that this soil fraction can affect plant metabolism directly.

999 VERBEEK, A. A. and URE, A. M. Improved precision by servomechanical stabilization of cyanogen band emission in a nitrous-oxide/acetylene flame. *Anal. Chim. Acta.*, 1978, **102**, 195-199.

An improvement in the precision of atomic emission spectrometry with the nitrous-oxide/acetylene flame is demonstrated for elements such as aluminium and barium when the cyanogen band intensity is stabilized. One channel of an IL751 atomic absorption/emission spectrometer is used to measure the intensity of the aluminium (396·2 nm) or barium (553·5 nm) lines while the second channel is used to measure the cyanogen band-head at 387·2 nm. The output of the latter channel is fed to a pen-recorder whose servo-motor is used to control the acetylene supply to the burner in such a sense as to stabilize the cyanogen band emission intensity. The consequent improvement in the constancy of flame conditions is reflected in an improvement in precision of measurement, shown here for atomic emission, but which should also be applicable to atomic absorption spectrometry.

1040 VIOLANTE, P. (Univ. degli. Studi, Napoli, Italy) and TAIT, J. M. Identification of imogolite in some volcanic soils from Italy. *Clay Miner*, 1979, **14**, 155-158.

The amounts of materials with the imogolite structure in some Italian volcanic soils have been semi-quantitatively estimated in the <0·4 um clay fractions on the basis of the absorbance of the 348 cm^{-1} band in the infrared spectra. Electron diffraction patterns showing diffuse rings provide evidence of proto-imogolite, a gel-like material having structural analogies with imogolite. The presence of such a poorly ordered component could be indicative of conditions unfavourable for imogolite formation.

1031 WARNE, S. St. J. (Univ. Newcastle, Australia) and MITCHELL, B. D. Variable atmosphere DTA in identification and determination of anhydrous carbonate minerals in soils. *J. Soil Sci.*, 1979, **30**, 111-116.

The identification and determination of carbonate minerals such as calcite and dolomite in soils can be greatly improved by suitable control of the atmosphere around the specimens. Thus, in a carbon dioxide atmosphere amounts to carbonate of just over 0·1 mg can be detected in a 50 mg sample and the temperatures and shapes of the decomposition peaks facilitate identification of the carbonate mineral. The technique is particularly valuable in mineralogical and pathological studies.

WEST, T. S. Practical developments in atomic fluorescence spectroscopy. *Proc. Anal. Div. Chem. Soc.*, 1976, **13**, 266-271.

Some aspects of practical import for the application of atomic fluorescence spectroscopy to trace analysis, are reviewed. These include the factors in the equation that relates the analytical signal to the concentration of the trace constituent, and those relating to the choice of the atomic line, atomization technique, and spectral line source. Recent work on the preparation of temperature stabilised electrodeless discharge lamps is discussed and the possibilities of applying non-dispersive atomic fluorescence spectrometry using reflectance optics with time resolution of the analytical signals for binary mixtures of elements.

WEST, T. S. Some early British contributions to atomic spectroscopy (1672-1835). *Proc. Anal. Div. Chem. Soc.*, 1977, **14**, 177-179.

In this paper the contributions made to analytical atomic spectroscopy between the years 1672 and 1835 by British scientists from Newton to Wheatstone are discussed briefly against the background of their times and personalities.

1000 WEST, T. S. Some recent developments in atomic fluorescence spectroscopy. *Pure Appl. Chem.*, 1978, **50**, 837-843.

The merits and demerits of atomic fluorescence spectroscopy as a trace metal analytical technique are compared to those of atomic absorption and emission analysis principally from an inductively coupled RF plasma source. An assessment is made of the possible impact of the use of coherent laser radiation to stimulate atomic fluorescence with the possible onset of super-radiant atomic fluorescence phenomena. The paper also reviews the atomizers most suitable for fluorescence work and the principal instrumental modes of fluorescence.

1025 WEST, T. S. Trace element distribution. *Educ. Chem.*, 1979, **16**, 62-65.

A brief account of some aspects of the spectrochemical investigation of trace element deficiencies in soils and plants written for teachers of chemistry at secondary and tertiary levels.

979 WILSON, M. J. Occurrence of thaumasite in weathered furnace slag, Merthyr Tydfil. *Mineralog. Mag.*, 1978, **42**, 290-291.

Thaumasite, an unusual hydrated calcium silicate containing sulphate and carbonate occurs in abundance in furnace slag at Merthyr Tydfil, South Wales. The mineral has a finely fibrous nature and was formed during the weathering of the slag.

1018 WILSON, M. J. Penecontemporaneous weathering of the old red sandstone in the Midland valley of Scotland — discussion. *Scot. J. Geol.*, 1979, **15**, 66-67.

A recent paper on the source of the pigmentary iron oxides of the Scottish old red sandstone is critically discussed. It is concluded that intrastratal alteration of iron-bearing silicate minerals has played little or no role in the formation of these iron oxides.

1001 WILSON, M. J. and BERROW, M. L. The mineralogy and heavy metal content of some serpentinite soils in north-east Scotland. *Chem. Erde.*, 1978, **37**, 181-205.

Four soils developed on serpentinite-derived glacial drift were investigated in order to elucidate the relationship between mineralogy and heavy metal (nickel, cobalt and chromium) content. The distribution of the heavy metals in the profiles varied erratically, but could be related to differences in the relative amounts of serpentinic to non-serpentinic material as well as to weathering transformations involving soil minerals.

986 WILSON, M. J. and CLARK, D. R. X-ray identification of clay materials in thin sections. *J. Sediment, Petrol*, 1978, **48**, 656-660.

A method is described enabling complementary optical and x-ray powder diffraction observations to be made on small areas of fine grained material in soil thin sections.

AGRICULTURAL RESEARCH INSTITUTES IN GREAT BRITAIN

The research programmes of the following agricultural research institutes supported by public funds are co-ordinated by the Agricultural 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 of the institutes concerned.

ARC Institutes

Animal Breeding Research Organisation	King's Buildings, West Mains Road, Edinburgh, EH9 3JQ.
Institute of Animal Physiology	Babraham, Cambridge, CB2 4AT.
Institute for Research on Animal Diseases	Compton, Newbury, Berks, RG16 0NN.
Food Research Institute	Colney Lane, Norwich, NR4 7UA.
Meat Research Institute	Langford, Bristol, BS18 7DY.
Poultry Research Centre	King's Buildings, West Mains Road, Edinburgh, EH9 3JS.
Letcombe Laboratory	Letcombe Regis, Wantage, Oxfordshire, OX12 9JT.
Weed Research Organisation	Begbroke Hill, Sandy Lane, Yarnton, Oxford, OX5 1PF.

State-aided Institutes (Scotland)

Animal Diseases Research Association	Moredun Institute, 408 Gilmerton Road, Edinburgh, EH17 7JH.
Hannah Research Institute	Ayr, KA6 5HL.
Hill Farming Research Organisation	Bush Estate, Penicuik, Midlothian, EH26 0PH.
Macaulay Institute for Soil Research	Craigiebuckler, Aberdeen, AB9 2QJ.
Rowett Research Institute	Bucksburn, Aberdeen, AB2 9SB.
Scottish Institute for Agricultural Engineering	Bush Estate, Penicuik, Midlothian, EH26 0PH.
Scottish Horticultural Research Institute	Invergowrie, Dundee, DD2 5DA.
Scottish Plant Breeding Station	Pentlandfield, Roslin, Midlothian, EH25 9RF.

State-aided Institutes (England and Wales)

Animal Virus Research Institute	Pirbright, Woking, Surrey, GU24 0NF.
East Malling Research Station	East Malling, Maidstone, Kent, ME19 6BJ.
Glasshouse Crops Research Station	Worthing Road, Rustington, Littlehampton, Sussex, BN16 3PU.
Grassland Research Institute	Hurley, Maidenhead, Berks, SL6 5LR.
Houghton Poultry Research Station	Houghton, Huntingdon, PE17 2DA.
John Innes Institute	Colney Lane, Norwich, NOR 7OF.
Long Ashton Research Station	Long Ashton, Bristol, BS18 9AF.
National Institute of Agricultural Engineering	Wrest Park, Silsoe, Beds, MK45 4HS.
National Institute for Research in Dairying	Shinfield, Reading, Berks, RG2 9AT.
National Vegetable Research Station	Wellesbourne, Warwick, CV35 9EF.
Plant Breeding Institute	Maris Lane, Trumpington, Cambridge, CB2 2LQ.
Rothamsted Experimental Station	Harpenden, Herts., AL5 2JQ.
Welsh Plant Breeding Station	Plas Gogerddan, Aberystwyth, Dyfed, SY23 3EB.
Wye College, Department of Hop Research	Ashford, Kent, TN25 5AH.