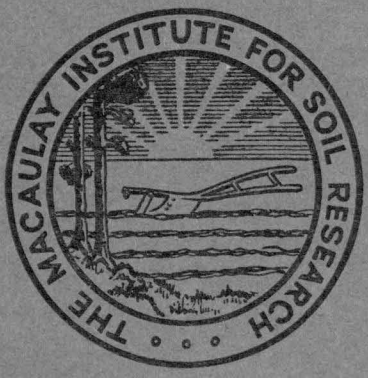
THE MACAULAY INSTITUTE FOR SOIL RESEARCH

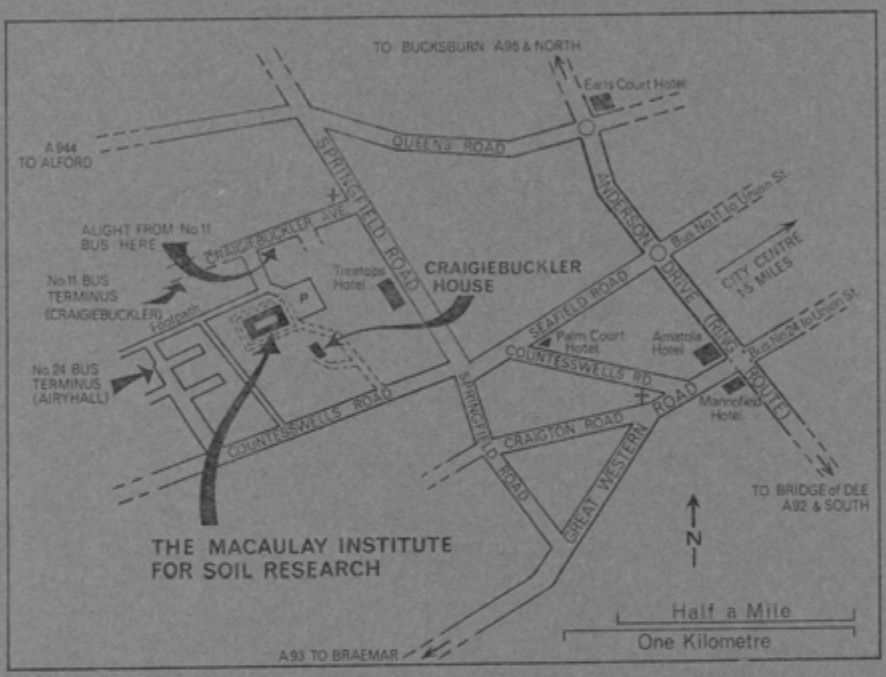


FOUNDED 1930

1974-1975 ANNUAL REPORT

No. 45

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



The Macaulay Institute is situated on the western outskirts of Aberdeen, about three miles from the centre of the city. The main entrance is on Countesswells Road, but visitors using public transport should take either the Corporation Bus Route 11 to the point indicated, from which the Institute is reached in a few minutes by Craigiebuckler Drive, or 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, 1974 to 30th September, 1975. The staff list is that current in November/December, 1975 and the Introduction is similarly updated. The report was published in May, 1976.

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

Printed by SCOTTISH & UNIVERSAL NEWSPAPERS LTD., Galashiels

THE MACAULAY INSTITUTE FOR SOIL RESEARCH

CRAIGIEBUCKLER, ABERDEEN

(Founded 1930)

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1974-75

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STAFF

1974-75

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† PROFESSOR T. S. WEST, B.Sc., Ph.D., D.Sc., C.Chem., F.R.I.C.

Deputy Director—

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G. F. BROCKLEY.
MRS P. FARMER—25/11/74-25/4/75.
MISS S. PATTERSON—appointed 15/7/75.
MISS C-A. DANIEL—appointed 1/8/75.
F. F. WARDEN.

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J. S. ANDERSON.
MRS O. J. L. PAULINE.

* Retired 30/9/75.

† Appointed 1/10/75.

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Mrs J. Shirriffs.
Mrs M. M. Procee.
J. W. Mitchell.
Miss Y. E. M. Gray.
Mrs A. M. Taylor—resigned 27/6/75.
Mrs D. S. Kennedy—18/11/74-22/8/75.
A. J. McPhee—appointed 28/10/74.
Miss A. Black—appointed 15/7/75.

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Miss C. L. Robertson.
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J. Fyfe.
Miss J. Milne.
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Miss A. M. Mowat.
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Miss J. W. Rutherford—appointed 21/7/75.
B. J. Burr—appointed 1/9/75.
I. Black—appointed 16/9/75.
Miss E. M. Gordon—appointed 22/9/75.
Miss E. M. L. Davidson—appointed 6/10/75.
G. Bruce—retired 31/10/75.
I. M. Still.
E. Lawson—appointed 1/10/75.

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MISS R. M. PATERSON.
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MISS M. H. CUMMING—resigned 31/7/75.
MRS L. M. REID—7/10/74-31/5/75.
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MISS A. H. THOMSON—appointed 8/9/75.

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I. SMITH—appointed 1/7/75.

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MISS M. G. SHERRIFFS.
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MRS M. M. JUSTICE.

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MISS C. IRELAND.
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MISS H. R. HUTCHISON.
MRS E. PIRIE—resigned 31/7/75.
MISS E. A. MACKAY.
MRS R. G. MCPHERSON.
MISS M. E. LEITH—resigned 25/10/74.
MRS G. COUTTS.
MISS D. B. THOMSON.
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MISS R. MACKENZIE—resigned 4/10/74.
MISS A. BIRNIE.
S. D. PORTER.
MRS C. CRAIGMYLE.
MRS H. M. DUNCAN.
MISS A. R. SHIRLEY—21/10/74-28/2/75.
MRS G. DUGUID—28/10/74-28/2/75.
MRS C. A. MORICE—appointed 1/4/75.
MRS J. STEWART—appointed 9/6/75.
MRS A. M. SOBEY—appointed 1/9/75.
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A. R. DOUGLAS.
J. S. MORRISON.
J. A. M. ANDERSON.
W. J. DUNCAN.

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MISS A. C. CROWTHER, B.Sc.—appointed 1/11/75.
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MISS A. MCDONALD.
MISS J. E. TAYLOR.
MISS L. STEVENSON.

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F. T. DRY, B.Sc.
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L. ROBERTSON, B.Sc.
J. MENZIES, B.Sc.—appointed 1/1/75.
N. A. DUNCAN, B.Sc.
G. HUDSON, B.Sc.
J. MACKAY, B.Sc.—resigned 13/12/74.
D. W. MERRILEES, B.Sc.—resigned 14/11/75.
C. G. B. CAMPBELL, B.Sc.
D. J. HENDERSON, B.Sc.
G. G. WRIGHT, B.Sc.
W. S. SHIRREFFS.
A. D. MOIR.
MISS S. SHERRIFFS.
MISS P. R. CARNEGIE.
C. M. MIDDLETON—resigned 22/11/74.
C. HALLIDAY—appointed 5/5/75.

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MRS R. NOBLE—deceased 5/12/75.
MRS L. GARDEN.

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J. H. NORMINGTON.
G. J. GASKIN.
A. I. A. WILSON.
J. A. MACDONALD.
R. A. BURNS.
R. RIDDELL—deceased 30/11/74.
R. D. MALCOLM—appointed 4/11/74.
G. SIM—appointed 10/2/75.

Photographer
J. MITCHELL, A.I.I.P., A.I.M.B.I.
D. J. RILEY.

Clerk of Works
G. FORBES.

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MISS E. J. COCKBURN.

Cashier
MISS H. T. G. DONALDSON.
MRS M. MILNE.

STAFF—*continued*

Personal Secretary to Director	MISS M. H. F. B. NICOL.
Office Staff	MRS S. M. WINTON.
	MRS P. LAING—appointed 26/5/75.
	MISS R. A. WILKIE—resigned 31/10/74.
	MISS A. REID—6/1/75-22/9/75.
	MISS M. H. DARGIE—resigned 28/3/75.
	MRS I. M. SHAND.
	MRS C. T. GARDEN.
	MRS A. C. MCDONALD.
	MRS A. KELLY—resigned 22/11/74.
	MRS E. E. HARVEY—appointed 25/11/74.
	MRS L. MCLOUGHLIN—appointed 21/4/75.
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Storekeeper	A. S. RIDDOCH.
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Attendant	E. M. S. CRUICKSHANK.
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	H. SHAW.
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	S. W. MALCOLM—appointed 11/11/74.
	W. L. W. ROSS—appointed 16/12/74.
	F. B. ADAM—appointed 4/2/75.
	R. A. R. CLARKE—appointed 11/8/75.

VISITING RESEARCH WORKERS

A. S. DE ENDREDY (FAO, Rome, Italy).

H. K. EL-KHOLY (Faculty of Science, Sana'a University, Yemen Arab Republic).

J. L. NEAL (Canada Department of Agriculture Research Station, Lethbridge, Alberta, Canada.

R. L. PARFITT (Department of Chemistry, University of Papua and New Guinea).

K. W. PERROTT (Department of Agriculture, Ruakura Soil Research Station, Hamilton, New Zealand).

J. A. ROBERTSON (Department of Soil Science, The Alberta Institute of Pedology, University of Alberta, Edmonton, Canada).

H. H. TOK (Ecole Nationale Supérieure d'Agronomie et des Industries Alimentaires, Nancy, France).

S. UZIAK (Instytut Naak o Ziemi, Uniwersytet Marii Curie-Sklodowskiej, Lublin, Poland).

CONTENTS

INTRODUCTION

Dr R. L. Mitchell, fourth Director of the Institute, retired from the Directorship on 30th September 1975 after having held the post since July 1968. His successor is Professor T. S. West who relinquishes the Chair of Analytical Chemistry at the Imperial College of Science and Technology (University of London) which he has held since its establishment in 1965.

Dr Mitchell, a native of Edinburgh, and a 1st class honours graduate of its University (1931), joined the newly founded Institute as a DOAS research student, working on the lime status of Scottish soils, and secured the Ph.D. degree of the University of Aberdeen for his work in 1934. A visit to ETH, Zurich during this time, to study soil science and colloid chemistry, kindled his interest in Lundegårdh's flame emission spectroscopy technique which he saw in operation there. Upon his return as the holder of a DOAS/ARC research grant, he persuaded Dr W. G. Ogg (now Sir William), the first Director of the Institute, to obtain funds for similar equipment. During this time and following his appointment as a member of the staff in 1937, he was responsible for building up the Institute's Department of Spectrochemistry which is now recognized as one of the foremost spectro-

Dr R. L. Mitchell, Dr A. B. Stewart and Sir William Gammie Ogg on the occasion of the Staff presentation to Dr Mitchell on 29th September 1975. All three have now been elected as Honorary Fellows of the Institute.

chemical laboratories in the world, especially in the context of the examination of agricultural and geological materials. He and his colleague Dr R. O. Scott, now Head of Spectrochemistry, quickly recognized the key problem of limited sensitivity in flame emission spectroscopy for heavy metals and consequently evolved the preconcentration technique for trace elements with which their names are internationally associated. In this way the Institute was able to achieve dramatic success in the determination of trace metals such as cobalt, copper, lead, molybdenum, nickel and zinc which were recognized by the late 1930s to be essential or toxic elements for plants or animals. The new techniques of atomic absorption and atomic fluorescence spectroscopy were also introduced with great effect at an early stage to the Institute under Dr Mitchell's guidance as were more sophisticated techniques such as spark-source mass spectrometry and Mössbauer spectroscopy. Staff have also been encouraged to use extra-mural facilities such as electron spin resonance, etc., when these have become available in sufficient proximity. As a result it is now possible to comment on the way in which these metals are bound in plants and soils, as well as to determine them at ever-lower concentrations.

Dr Mitchell was appointed Deputy to the Institute's second Director, Dr D. N. McArthur, in 1955 and in this capacity was largely responsible for the planning of the present Institute building which was opened in 1962 with a staff of 170 workers. He continued to serve in this capacity under the third Director, Dr A. B. Stewart, and became the fourth Director in 1968. During his long service and particularly during his Directorship he has carried the Institute successfully and triumphantly through the period of its greatest physical growth and scientific development. Despite the heavy and ever increasing administrative responsibilities involved, he has continued his personal research work in applied spectroscopy and has brought great credit and renown to the Institute. Amongst the honours bestowed on him are the Medal of the Royal Agricultural Society of England (1963) and the Gold Medal of the Society for Analytical Chemistry (1974); Dr Mitchell is the tenth recipient of the latter medal and is both the first agricultural scientist and the first Scot to receive the award.

Members of Council had had in mind for some time the desirability of preserving the connection of past Directors with the Institute and Dr Mitchell's retirement was taken as 'an occasion for inaugurating an Honorary Fellowship of the Macaulay Institute.' This honour was conferred simultaneously on 1st October 1975 on Sir William Ogg, Dr A. B. Stewart and Dr R. L. Mitchell.

Miss A. M. B. Geddes who has been Librarian since 1945, and who has given such invaluable service to the Institute during the past 30 years, retired on 30th August 1975. It is a pleasure to record the Institute's gratitude to her with our best wishes for her future in retirement. We also welcome her successor, Mrs J. M. D. Alcock, who was formerly Deputy Librarian at the Marine Laboratory, Aberdeen.

Members of Council and staff learned with regret of the death of Sir Edmund Hirst on 29th October 1975. Sir Edmund had served as a Member of Council from 1948 to 1969 and was Convener of the Staff Committee

where his interest in their work was greatly appreciated by all members of staff.

It is with much regret that the premature death is recorded of Mrs R. Noble who served the Institute as Assistant Librarian from October 1960 to December 1975.

Equally sadly the sudden death of Mr R. Riddell on 30th November 1974 is also recorded. Mr Riddell had been a much respected member of the Technical Services staff since 1956.

On 28th November 1974, Craigiebuckler House was formally re-opened by Sir William Ogg, the first Director of the Institute. After being largely unoccupied since 1962, Craigiebuckler House was renovated by means of a capital grant made available by the Department of Agriculture and Fisheries for Scotland, who are responsible for commissioning and financing the work of the Institute by means of an annual grant-in-aid. The South Block has been assigned to general Institute use, and includes the Auditorium, Council Room, Conference Rooms, Staff Common Room, other Service Rooms and three rooms to be used by the Staff Association for staff amenities. The Staff Common Room was furnished in part by funds made available by Mrs H. W. K. Hale, a daughter of the Founder, and has been designated the Macaulay Room. Two young horse-chesnut trees in the forecourt were donated by the Staff Association in National Tree Planting Year and replace mature trees lost in the gale of 1953, when over 70 trees in the grounds were blown down. The North Wing is being used to accommodate the Department of Soil Survey which has now moved out of the main building.

A new soil store, constructed during the year, has solved the problem of storage of soil profile samples and of catering for similar samples likely to be collected in the foreseeable future. These samples, characterized in the field by Soil Survey and in the laboratory by Pedology, have been accumulated since the early 1930s and form a very valuable collection from which samples with specific characteristics can be selected for research purposes by any department of the Institute.

In October 1974 the Soil Science Committee of the Arable Crops and Forage Board of the Joint Consultative Organisation for Research and Development in Agriculture and Food, held their meeting at the Institute under the Chairmanship of Professor E. W. Russell. The members of the Committee took the opportunity to visit the laboratories in the afternoon preceding the meeting.

The Clay Minerals Group of the Mineralogical Society of Great Britain and Ireland met in April at the Institute. The meeting, which was attended by 35 delegates from the UK, France, Italy, Norway and Holland, had as its theme 'Transformation and alteration of clay minerals' and discussed several aspects of weathering in soils. On the second day a field excursion was organised to sites showing deep weathering of rock.

A visit to the Institute was made in June by a delegation of five Soviet Agricultural Scientists under the agreement on Anglo-Soviet Co-operation in Agricultural Research. The delegation was led by Mr A. A. Konygin, Chief of the External Relations Department, Ministry of Agriculture, and

the other members were Dr V. A. Tikhonov, USSR Academy of Agricultural Sciences, Novosibirsk, Dr M. A. Sidorov, Head of the Microbiology Laboratory, USSR Institute of Experimental Veterinary Science, Moscow, Dr K. V. Novozhilov, Director of the All-Union Research Institute of Plant Protection, Leningrad, Dr P. G. Ampilogov, Senior Specialist, Ministry of Agriculture, accompanied by Dr V. Nagorny, Dr L. Overchuck and Dr A. Chugunov, USSR Embassy, London, and Mr J. G. Brotherston of the Department of Agriculture and Fisheries for Scotland, Edinburgh.

Short-term visitors from twenty different countries visited the Institute during the year and facilities were provided for longer-term workers from Canada, New Zealand, Papua and New Guinea, Poland, Turkey and the Yemen Arab Republic.

Dr V. C. Farmer (Spectrochemistry) has edited and contributed five chapters to the recently published 'The Infrared Spectra of Minerals' and in recognition of his Editorship, the Mineralogical Society met the expenses involved in his attendance at the International Clay Conference in Mexico City in July 1975.

Dr R. O. Scott (Spectrochemistry) accepted an invitation to give two lectures at a Symposium of the Institute for Petrologi, University of Copenhagen in September 1975. This Symposium marked the Twenty-fifth Anniversary of the installation of their spectrochemical laboratories. The expenses of this visit were met by the organizing body.

Several members of staff made profitable visits to research establishments and attended scientific conferences abroad with the aid of funds made available by the Agricultural Research Council. Mr J. C. Burridge (Spectrochemistry) attended an FAO/IAEA Symposium on 'Isotope Ratios as Pollutant Source and Behaviour Indicators' in Vienna, Austria in November 1974. Mr R. A. Robertson (Pedology) attended a Symposium on Peat in Agriculture and Horticulture (Commission III, International Peat Society), in Tel Aviv, Israel in June 1975. Dr J. F. Darbyshire (Microbiology) visited the Institut für Wissenschaftlichen Film, University of Göttingen, Federal German Republic for one week in June. Dr P. C. DeKock (Plant Physiology) attended the XIIth International Botanical Congress in Leningrad, USSR in July. Dr P. D. G. Cradwick (Pedology) attended the Xth International Congress of Crystallography in Amsterdam, The Netherlands, in August. Mr R. H. E. Inkson (Statistics) attended a meeting of the International Society of Soil Science, Commission V, Working Group on Soil Information Systems in Wageningen, The Netherlands, in September. Mr A. H. Knight (Soil Fertility) attended the VIth Annual Meeting of the European Society of Nuclear Methods in Agriculture, Montpellier, France, in September. Dr P. W. Dyson (Soil Fertility) attended the VIth Triennial Conference of the European Association for Potato Research on Quality in Potatoes, Wageningen, The Netherlands, in September and thereafter visited the Departments of the Agricultural University, Wageningen, and the Institute of Soil Fertility, Haren, Groningen. Dr R. O. Scott (Spectrochemistry) attended the XVIIIth Colloquium Spectroscopicum Internationale, Grenoble, France, in September.

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

100	Pedology	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 interdepartmental 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.

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.

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 Chemistry of soil-organic-matter: mineral complexes.

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 enables other departments to investigate 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 and to ascertain its contribution to the physical structure and chemical behaviour of soils and its 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 breakdown 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.

501 Incidence and characteristics of lytic microorganisms in the root region of cereals.

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

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

504 Interrelationships of soil protozoa and bacteria inoculated on axenic (microorganism free) plant roots.

505 Interrelationships of soil protozoa with other soil microorganisms.

506 Microbial degradation of soil organic matter as influenced by clay minerals.

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

508 Soil-borne fungal parasites.

509 Soil protozoa in the metabolism of soil organic matter.

510 Investigation of soil protozoan populations.

511 Physiology of actinomycetes in soils.

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 agricultural, horticultural and forestry purposes.

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.

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.

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.

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

612 Soil physical conditions and crop growth.

701 Design and analysis of experiments including crop response functions and the fitting of response surfaces.

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 of radioactive 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 radioactive facilities.

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

5703 Data preparation and computer processing.

1. PEDOLOGY

The main aim of the work of the department continues to be to obtain a better understanding of the origin and properties of the complex soil system by the methods of pure science.

In assessing the soil resources of Scotland a systematic survey of peat deposits is of considerable importance. Current practice is for the peat survey team to enter an area once the mineral soils have been mapped and the areas of peat delineated, but in areas where peatland is considerably more extensive than mineral soils it may be appropriate to reverse this procedure. Unfortunately, such areas present considerable access problems, since few roads or tracks exist and, even with a tracked vehicle, the absence of pronounced topographical features makes it difficult to assess the exact location. The encouraging results achieved in pilot surveys, using a recently acquired stereo-plotter in conjunction with air photos and limited ground traverse and control, indicate that much improved and more rapid methods of mapping can be developed with the use of computer facilities. This aspect is being further investigated in view of the consequent increases in accuracy and productivity in terms of area covered.

Samples relevant to research projects have been examined for other departments and outside bodies by specialized techniques available in the department: in some instances collaborative studies have ensued. Close connections have been maintained with the Department of Agriculture and Fisheries for Scotland, the Forestry Commission, the Highlands and Islands Development Board, the British Steel Corporation and various other bodies interested in the survey and utilization of peat resources. In accordance with Institute responsibility for information on peat resources and development, advice has been given to many organizations and individuals.

Dr K. W. Perrott, Ruakura Soil Research Station, Hamilton, New Zealand, has completed his studies on poorly ordered inorganic components of soils and Dr A. S. de Endredy, F.A.O., Rome, has assisted in the work of the department.

Members of staff have attended meetings of, *inter alia*, the ARS Advisory Group on Electron Microscopy, of which Dr W. J. McHardy is a member, the ARS Mass Spectrometry Users' Group, the British Society of Soil Science, the Thermal Methods Group of the Chemical Society: Analytical Division, the Hill Land Use Ecological Studies Group and the Forest Soils Discussion Group. The April 1975 meeting of the Clay Minerals Group of the Mineralogical Society was held at the Institute and was attended by about 40 scientists, several coming from overseas.

Dr P. D. G. Cradwick participated in the Xth International Congress of Crystallography in Amsterdam and Mr R. A. Robertson attended a Symposium on Peat in Agriculture and Horticulture arranged by Commission III of the International Peat Society (IPS) in Israel in June as well as a Council Meeting of the IPS in Malmö, Sweden, later in the year.

CHEMISTRY AND MINERALOGY

Analytical and Morphological Studies

Chemical. Systematic physical and chemical analyses have been completed on soil samples collected by Soil Survey in 1972 and work is in progress on those collected in 1973. Soils collected in 1974 are being prepared for analysis. Some 5000 samples, including those tested for other departments and appropriate outside bodies, have been examined. Bromine treatment has proved to be an excellent method for oxidizing organic matter in extracts before analysis[1]. 101, 104, 105, 112, 204, 504, 801

Studies on seasonal variation in the major-element content of the soil solution of two gley profiles of the Countesswells Association, referred to in last year's Report, are being supplemented by analysis of water at different levels in a cut-over peat bog. No entirely satisfactory explanation has yet been found for the high sodium content (*ca* 7·5 ppm Na) of the water from the peat. 101, 111

Equipment for investigating the significance of seasonal soil-atmosphere changes (Annual Report, No. 42, 1971-72) has been improved, samples being withdrawn into glass syringes which are transported to the laboratory and connected directly to the analytical equipment. Nitrogen, oxygen, carbon dioxide, argon and methane are determined by mass spectrometry and trace hydrocarbons, such as ethylene, by gas chromatography. Results have yet to be analysed in detail. 108

X-ray fluorescence spectrometry has been employed to analyse a wide range of soil and plant materials and acquisition of a gold-anode X-ray tube has extended the usefulness of the method by enabling the determination of trace amounts of certain elements such as copper, 2·3 ppm of which was detected in one peat sample. 104, 107, 403, 507

Thermoanalytical. The thermoanalytical techniques of differential thermal analysis (DTA) and thermogravimetry have wide application in pure and applied chemistry[2, 3] as well as in soil mineralogy[4] and are extensively used in the department. Recent observations with these techniques have shown that exchangeable anions can affect the dehydroxylation reaction of goethite and exchangeable cations the thermal behaviour of humic acid separated from a podzolic soil. Both these effects are receiving further attention. DTA has also proved useful in examining complex aluminium nitrates the structure of one of which (aluminium iodate nitrate hexahydrate) has been shown by single-crystal X-ray diffraction techniques[5,6] to have aluminium ions present in the form $Al(H_2O)_6^{3+}$. This observation may be relevant to aluminosilicate formation, since the compound concerned also crystallizes from a solution containing a mixture of ions. 103, 105, 106, 107

Electronoptical. The micromorphology of the surfaces of soil structural units and of concretions or pseudoconcretions formed during weathering is well revealed by scanning electron microscopy, which, when combined with electron probe microanalysis, also enables the precise location and concentration of elements to be observed directly. A form of manganese concretion distinct from the leaf-like birnessite previously observed in soils

developed on lacustrine clay of the Tipperty Association[57] has now been identified: occurring as massive laths, it consists of a mixture of cryptomelane and hollandite and has a barium content of about 5 per cent. 103, 109

Scanning electron microscopy, electron probe microanalysis and X-ray diffraction, along with other techniques, have shown the spine-like projections on spores and sporangia of certain fungi to consist of calcium oxalate dihydrate[58]. 107, 109, 507

Soil Mineralogy

The weathering of minerals inherited from parent materials by the soil provides a source of nutrients for plants and leads to the formation of secondary minerals that are important in determining soil properties[5]. For these reasons, various particle-size separates are examined mineralogically and their nature compared with that of pure mineral components[6], such as oxides of silicon[7], so that discrepancies can be detected and evaluated. In connection with the problem of nitrogen fixation in soils, compounds containing molecular nitrogen have also been investigated structurally[8]. 103, 104, 105, 107, 109

Sand Fractions. The reactive nature of the coarse fractions of certain soils has been further illustrated in that the sand fractions of soils developed on tills derived from lavas of Old Red Sandstone (Devonian) age exhibit cation-exchange capacities comparable with or even exceeding those of the clay fraction[59, 60]. The high nickel contents of some soils derived from serpentinite could arise from weathering of a nickeloan pyroaurite present in the original rock[61] but unstable in the soil. 101, 103, 104, 207, 801

In the initial stages of weathering at depth in several granite profiles, substantial oxidation occurs before vermiculitization can be detected by X-ray diffraction. Moreover, electron probe microanalysis reveals that in some instances potassium depletion proceeds from the centres of flakes rather than from the peripheries, as is usually believed. 103, 104, 109

The nature of heavy minerals in soils and their importance in soil science have recently been reviewed[9]. 103, 104

Clay Fractions. Because of its small particle size and consequent large reactive surface area, the clay fraction has considerable influence on soil behaviour. Its mineralogy, as elucidated by instrumental and chemical techniques, can also yield information on the surface properties of soils and on the mechanism of soil formation. Systematic mineralogical examination of clay fractions of soils from the Island of Mull (Sheet 35/36/43/44/51/52) has revealed that the predominant crystalline clay mineral present is a trioctahedral interstratified vermiculite-chlorite and that soils derived from basalt contain much non-crystalline inorganic material. Theoretical studies on the types of X-ray powder pattern given by various interstratifications[10] continue to be of great assistance in the identification of difficult species. 103, 105, 107, 801

In soils of the Countesswells Association, developed on granitic till, a platy type of halloysite is common, whereas in those on tills derived from basic igneous rocks the more familiar tubular type predominates: the

reasons are as yet unclear. The tubular halloysite in a poorly drained soil (Myreton series) of the Insch Association is dehydrated at the surface, but becomes more hydrated with depth. The serpentine minerals chrysotile, lizardite and antigorite have all been identified in a freely drained soil (Leslie series) of the Leslie Association, developed on a till derived mainly from serpentinite. According to electronoptical observations, lizardite converts to chrysotile on weathering by the rolling up of crystal plates from edges or along fractures, especially towards the surface. The clay fraction of a peaty podzol developed on till derived from chloritic schists near Loch Awe, Argyllshire, has a titanium dioxide content of about 25 per cent, present mainly as crypto-crystalline anatase formed by weathering of sphene[62]. The C horizons of some, probably sedentary, mountain soils developed on biotite-cordierite hornfels in the Merrick Hills of the Southern Uplands are high in gibbsite (up to 2 per cent) which may have resulted from preglacial weathering. The absence of gibbsite in the upper horizons presumably reflects the influence of post-glacial pedogenic conditions.
103, 104, 107, 109, 801

To obtain a better understanding of the significance of the clay mineralogy of Scottish soils, some soils from Australia[11], New Zealand, New Guinea[12], Egypt and South Yemen have also been investigated. 103, 105, 107, 109, 207

Clay: Organic Matter Complexes

A decrease in the amount of chlorite towards the surface in the clay fractions of an acid soil developed on till derived from chlorite schist in Argyllshire could be caused by the chlorite being susceptible to attack by organic acids. This hypothesis receives support from X-ray diffraction results which have shown that the chlorite in a chlorite-rich clay fraction from the C horizon of the profile decreases in amount after only a fortnight's contact with a solution of fulvic acid separated from mor humus. 104, 105

The fact that oxidation-reduction cycles occur during the decomposition of iron-phenolic chelates to iron oxides is of significance from the viewpoint of the gleying phenomenon[13]. 105

Surface Properties of Soils and Clays

Gas absorption studies have revealed that large numbers of micropores less than 1 nm in size occur in allophanic clays separated from soils developed on volcanic ash and pumice. These micropores contribute considerably to the surface areas measured by gas adsorption and their presence accounts for differences between these and surface areas measured by other techniques, such as ethylene glycol sorption. The sorption of carbon dioxide on goethite surfaces has been investigated and related to sorption of anions such as phosphate[14]. 106, 207

Earlier studies have shown that fluoride ions release much larger amounts of hydroxyl ions from non-crystalline inorganic materials than from crystalline clay minerals. A rapid technique employing sodium fluoride solution at a fixed pH has been devised and statistical analysis of results has shown that the amount of hydroxyl ions released correlates well with the amount of alumina removed by 5 per cent sodium carbonate solution

at room temperature[63]. Further study of the reaction has indicated that the amount of hydroxyl ions released by fluoride at high pH values (> 8) can be used to assess the alumina content of the gel and is related to the phosphate sorption capacity. 105, 5703, 801

Organic and Biological Materials

Rapid pyrolysis of soils *in vacuo* followed by mass spectrometric examination of the volatile products has already been established as a valid method of distinguishing humus types[15, 16]. The introduction of a gas chromatograph between the pyrolysis unit and the mass spectrometer, as mentioned in last year's Report, has, however, provided a much more versatile instrument capable of yielding very detailed information. Thus, it has been established that mor humus from podzols yields more furfurals and phenols than pyrrole whereas brown podzolic soils yield relatively more pyrrole[64]. In a survey of variation in the nature of the organic matter associated with the broad class of brown forest soils it has been established, in collaboration with Soil Survey, that differences in products of pyrolysis correlate with soil pH, base saturation and climatic variables. Moreover, the organic matter associated with a range of New Zealand soils with similar vegetational cover and parent material has been found to be strongly influenced by climate[65]. 107, 108, 303, 801

Elucidation of the crystal structure of maleic hydrazide, a growth inhibitor widely used in agriculture, by single-crystal X-ray diffraction techniques has yielded information of value in determining its mode of action[66]. 105

PEAT AND FOREST SOILS

Peat Survey and Evaluation

Deep peat, which covers some 800,000 ha (2 million acres) or 10 per cent of the area of Scotland, is not only a medium that could be more intensively developed for agriculture, forestry and other forms of land use, but is also a very considerable reserve of raw materials for industrial and other uses. Accordingly, peat survey, classification and evaluation are designed to provide information of practical as well as scientific importance. Results are incorporated in Soil Survey memoirs and in more detailed maps and reports for areas scheduled for development or with development potential. 112, 113, 801

Survey techniques, including topographical, stratigraphical, botanical and photogrammetric studies, are also employed to support investigations on site capability[67], peatland drainage[68], bog cultivation and afforestation[69] and the production and utilization of peat for horticulture. 110, 111, 114, 802

Acquisition of a stereo-plotter (Wild B8S Aviograph has greatly advanced aerial photo-interpretation and has initiated photogrammetric map plotting in the Institute. From overlapping pairs of vertical aerial photographs the stereoscopic device creates an illusion in space of a magnified relief model of the terrain, thus greatly assisting observation, measurement and interpretation. This facility, when fully developed, should markedly increase survey output in that peat boundaries, contours and slopes as well as

locations of boreholes and such features as cuttings, dubh lochs and erosion channels can be speedily and accurately transferred to base maps with the minimum of field work, thus eliminating the need for time-consuming topographic surveys. A reconaissance survey to provide basic information has been carried out in Lewis and Harris and, with the aid of the stereo-plotter, detailed maps showing the nature and extent of peat cover are now being prepared. 112

The facilities for rapid co-ordination of information provided by the computer and graph plotter in the Department of Statistics has not only enabled digitization, storage and multivariate analysis of the results of previous surveys, but also a degree of semi-automated mapping that it is hoped to develop in future. 112, 5703

Work has progressed on devising a more comprehensive and meaningful system of peatland classification. Sites representative of a wide range of mire types have been studied around Stranraer (Sheet 1/2/3/4), in the Stirling area (Sheet 39) and in the Lothian and Border regions (Sheets 24, 25, 26, 33/34). The relative importance of characteristics such as phyto-sociology, hydromorphology and stratigraphy as classification criteria is being assessed and representative cores have been taken for sub-fossil analysis. A provisional peatland classification system is being applied to two areas (near Nairn and Stirling) in a pilot study intended to test the practicability of the system. 111, 112

Cartographic work and laboratory analysis of samples from the Nairn area (Sheet 84) have progressed satisfactorily. Close liaison with national and international agencies concerned with peat science and technology has greatly assisted staff in fulfilling their responsibilities for recording and providing information on many aspects of peat research and development. 112

Pollen Analysis and Quaternary Research

In collaboration with Soil Survey, attempts are being made to date periods of slope instability in upland areas from pollen analyses of the layered mineral and organic deposits that occasionally and locally overlie the normal soil profile. Sites for this work have been selected in the Cairngorms and the eastern Grampians. 113, 804

The date of formation of a peat deposit 4·7m deep, excavated during realignment work on the A9 Perth-Inverness road at the summit of the Slochd Pass, has been assessed by pollen analysis as the early Boreal Period (zone IV), some 9000 years ago. During this time-span the area appears to have carried a cover of forest dominated originally by birch, then by pine and finally again by birch. 112, 113, 802

Organic material which has accumulated on the bottom of certain lakes can be a rich source of preserved pollen and spores. Deposits of this nature at Loch of Strathbeg near Peterhead and at Loch of Lumgair near Stonehaven have been sampled for examination. Lacustrine sediments can be obtained by conventional peat sampling methods if they lie in a completely overgrown basin, as at Lumgair, and by sub-aqua techniques if under water, as at Strathbeg. 113

Computer techniques, devised in collaboration with the Department of Statistics, are proving successful in processing and collating pollen analytical results. A method of preparing pollen diagrams that facilitates regional comparisons has been tested using arboreal pollen counts from a range of Scottish peat deposits[70]; results are encouraging. 113, 5701

Root and Moisture Studies in Peat

The experiment established in 1963 at Lon Mor, Inverness-shire, to study the effect of water-table depth on the establishment and growth of coniferous trees on deep blanket peat continues to give valuable information. Prior to canopy closure, tree height could be related linearly to depth of water-table and thereafter to the air volume of the peat. Other parameters of growth, including tree weight and foliage area, increased exponentially. The nutrient status of the trees was broadly related to treatment but decreased progressively, reaching very low values and showing no improvement as a result of the drying and increase in rooting volume that followed canopy closure[71]. In Spring 1975, the Sitka spruce planted in 1972 over one-third of each plot was still suffering so severely from heather competition, particularly in the drier plots, that the heather was removed. To date less than 25 per cent of the spruce has survived under waterlogged conditions but, in the other four treatments, with water levels at 9, 17, 23 and 35cm below the surface, almost 100 per cent establishment has been achieved despite the severe heather check mentioned above. Oxygen concentrations in the peat at depths of 5, 10, 15, 30 and 50cm below the surface have been monitored at monthly intervals during the past year and relationships between aeration patterns, water-table depth and root distribution are being examined. Although the water-table levels in the five plots are at a fairly constant depth from the surface all the year round, there is considerable seasonal fluctuation in the concentration of oxygen at different depths. 110, 117

Peat Standards and Glasshouse Investigations

Characterization and evaluation of horticultural peats and peat products[72] have continued in collaboration with national and international standards organizations. Although agreement on standard analytical procedures for determining the physical properties of peat substrates is still awaited, progress has been made on peat classification. 114

A fifth successive crop of tomatoes has been grown in the six mono-ingredient peat substrates referred to in last year's Report. In addition to continuation of the loss of plant vigour and reduction in fruit yield first noted in 1974, there has also been an appreciable deterioration in the structure of the peat as reflected by a reduction in pore volume. 114

Results of an investigation, in collaboration with the Department of Plant Physiology, on the incidence of blossom-end-rot in tomatoes grown in pure peat, indicate that the condition is aggravated by water stress. Samples of fruit and foliage have been taken at several stages of the crop to examine the effect of moisture status on mineral uptake and distribution in the plants. 114, 402

Nutrient Uptake from Forest Soils

Studies on the effect of soil type and fertilizer input on the rate of nutrient cycling through the soil-tree system have continued with the establishment of a further field experiment at Kershope Forest near Langholm, the fifth in the planned series of six referred to in last year's Report. All these experiments are in 20-30-year-old Sitka spruce and the soil types range from acid brown forest soils through surface-water gleys and peaty gleys to deep peats. Preliminary results from the older experiments, largely on brown forest soils, indicate the possibility of tree growth responses to nitrogen and potassium fertilizers, but none as yet to applied phosphate. 115, 117

Investigations on the relationship between nutrient cycling and tree growth in nitrogen-fertilized Corsican pine at Culbin (Laigh of Moray Forest) are now largely complete. A striking feature has been the extent to which this tree crop has trapped air-borne nutrients[73]. Thus, in addition to gross rainfall-carried input to a horizontal surface, the trees filter out a further 250 per cent potassium, 120 per cent calcium, 80 per cent magnesium and 60 per cent sodium. Although ignored in previous studies, aerosols clearly make a significant contribution to the soil-nutrient capital, the level of input presumably varying with the type of vegetational cover. Nitrogen input from aerosol, on the other hand, is insignificant. 115

In view of the low input of nitrogen in aerosol and the small amounts released by the trees into rainwater, the return of nitrogen to the soil is primarily by litter fall. As nitrogen concentration in newly fallen litter can be directly related both to the concentration in top-whorl foliage and to tree-growth, analysis of needle-litter could be a useful management technique for identifying those crops likely to show a worth-while response to nitrogen fertilizer[74]. Diagnosis of nitrogen deficiency, however, is complicated by several factors, such as variation in the relationship between growth and foliar nitrogen level with age. A range of glasshouse and field studies on Corsican pine suggests that the level of nitrogen associated with maximum growth declines until canopy closure but then increases. 117

Nitrogen fertilizer applied to the pole-stage Corsican pine at Culbin increased the foliage biomass, initially through increased needle retention and subsequently through the production of more numerous and larger needles[75]. In addition, there was a very rapid increase in net assimilation rate. A series of regression equations has been prepared to predict growth of new foliage, nutrient immobilization, release, etc.; from these the rates of nutrient uptake associated with different growth rates can be calculated. It has been shown that the nitrogen taken up and retained in tree tissues within a short period following fertilizer application is alone sufficient to explain the length of the growth response period[76]. Futhermore, retention of fertilizer nitrogen in the ecosystem was complete up to a rate of 252 kg per ha applied nitrogen, but thereafter decreased linearly. 115, 117

On a freely drained humus iron podzol with a well-developed mor humus layer, the response of mature Scots pine to nitrogen fertilizer was somewhat confounded by variations in climate. The operative factor appears to be drought, the severity of which depends on short-term cyclic variations in rainfall and temperature. 117

Nitrogen Mineralization in Peat and Mor Humus

The effect of lowering the water-table in peat on the amount of nitrogen mineralized during incubation has already been established[17] and attention has now been turned to particle-size effects. The total nitrogen content of particle-size fractions obtained by wet-sieving peat increases as the particle-size diminishes but, at least for *Sphagnum Eriophorium* peat, the amount of mineral nitrogen obtained on anaerobic incubation at 30°C does not increase with decreasing particle size as might have been expected from the C:N ratios, which range from 30 in the fine fraction to 120 in the coarse. These observations are being further investigated under different incubation conditions and for different peats. 110, 116

Studies on the effect of peat type on mineralization have been extended to cover samples from two contiguous areas, one with natural vegetation and the other planted with lodgepole pine. Rates of mineralization of nitrogen and evolution of carbon dioxide at 30°C suggest that certain peat types contain a smaller amount of readily decomposable organic matter in the drier aerated peat beneath trees than in the unplanted peat. The consequent lower rate of carbon assimilation by the microbial biomass may explain the further observation that mineral nitrogen accumulates more rapidy during the early stages of incubation of planted than of unplanted peat. 111, 116

The long-term effects of lime and fertilizer on nitrogen mineralization rates in mor humos continue to be monitored by incubating samples taken annually from a Scots pine experiment at Culbin. Samples of untreated and NPK-fertilized litter and humus from beneath pole-stage Sitka spruce at Fetteresso (Mearns Forest) are also being incubated in both the laboratory and the forest to assess the effect of fertilization. 115, 116, 117

2. SPECTROCHEMISTRY

The work of the department has continued along lines similar to those described in previous reports and has involved the investigation of the distribution of trace elements in soils, soil profiles, clay minerals and plant materials and the examination of the composition and structure of the inorganic and organic components of soils. Many of the determinations of elements of known biological importance, especially in samples from areas where specific nutritional problems are suspected, are carried out by flame atomic emission and atomic absorption methods. Samples from research experiments are usually analysed for the maximum number of elements for which established spectrochemical techniques are available. The AEI MS702R spark-source mass-spectrometer installed during the previous year has made possible the determination of several elements which previously could not be detected and the appointment of Dr J. R. Bacon will hasten the development of techniques and the analysis of samples by this method.

A Perkin-Elmer 577 infrared spectrometer was installed during the year and has extended the frequency coverage beyond that of the Grubb Parsons Spectromaster, allowing an overlap with that obtained with the Beckmann RIIC FS720 Fourier interferometer.

Several visiting research workers have used the spectroscopic facilities available. Dr H. K. El-Kholy, Physics Department, Faculty of Science, Sana'a University, Yemen Arab Republic, determined the trace element distribution in various rocks from the Yemen and Dr R. L. Parfitt, Agriculture Department, University of Papua and New Guinea, studied the surface properties of aluminium and iron hydroxides. Short term visitors examined the use of direct photometry for the analyses of bauxites, and the distribution of heavy metals in peat.

At the invitation of the Institut for Petrologi, Copenhagen University, Dr R. O. Scott gave two lectures at a symposium to mark the twenty-fifth anniversary of the installation of their spectrochemical laboratories. He also attended the XVIII Colloquium Spectroscopicum Internationale held in Grenoble, France. Dr V. C. Farmer acted as a delegate of the Clay Minerals Group of the Mineralogical Society to the conference of the Association Internationale pour l'Etude des Argilles in Mexico and Mr J. C. Burridge attended the IAEA/FAO Symposium on Stable Isotope Ratios in Vienna. Contributions were made by members of staff to meetings of the Analytical Division of the Chemical Society held at Glasgow and St Andrews, to a Colloquium on Spark-Source Mass-Spectrometry held at the University of Strathclyde, to meetings of the Clay Minerals Group of the Mineralogical Society held at Aberdeen, to the British Society of Soil Science at Bangor, and to the Surface Reactivity and Catalysis Discussion Group and the Mössbauer Discussion Group of the Chemical Society at Edinburgh and Nottingham respectively; meetings of the DOE Working Party on the Disposal of Sewage Sludge to Land, the Scottish Direct Reading

Spectroscopy Group, the Inorganic Biochemistry group of the Dalton Division of the Chemical Society and the Interservices/DTI Panel on Spectroscopy were attended.

Trace Elements in Soils, Plants and Biological Materials

The main extracting agents in use for evaluating the trace element status of soils continue to be 0·5M acetic acid, neutral 1·0M ammonium acetate and 0·05M EDTA. The use of water as an extractant for boron and other elements in sewage sludges has also been investigated. In collaboration with the Institute's Department of Soil Fertility, the East of Scotland College of Agriculture and the West of Scotland Agricultural College, ten large samples from different soil series throughout Scotland have been obtained. These have been dried, sieved and mixed and await subsampling prior to distribution to the various centres where they will be used to check the validity of analytical results.

A paper reviewing trace element problems in Scottish soils has been published[18].

Soils and Soil Parent Materials. Work on the distribution of trace elements in soil profiles with iron and manganese pans has continued. It has been found that an indication of the amounts of different trace elements held in an organically complexed form can be obtained from the EDTA minus the acetic acid extractable content. In the iron pans of about forty profiles, the mean percentage of the total contents present in organically complexed form are for cobalt, copper, iron, lead, manganese, nickel and titanium *ca* 2, 22, 2, 7, 5, 2 and 0·5 per cent respectively, while in the upper L, F and H horizons of the same profiles they are correspondingly 11, 38, 32, 31, 26, 17 and 2·5 per cent. In these profiles the high contents of titanium and vanadium extractable by EDTA from the A horizons have been investigated by separating some of the soils into size fractions and extracting each with EDTA. The total and extractable contents of both elements increase with decrease in particle size, the clay fractions containing up to 420 ppm Ti and 27 ppm V extractable by EDTA. However, because the ratio of extractable to total titanium shows little change from coarse sand to clay this suggests that the extractable titanium is present as a secondary mineral coating on the soil particles. In contrast, the ratio of the extractable to total vanadium increases sharply and consistently in the clay fraction. Some of the B_1 and B_2 horizons of these profiles are described as cemented and in these, unusually high amounts (up to 4000 ppm) of acid-soluble aluminium (acetic acid minus EDTA extractable) have been found, suggesting that aluminium is involved in the cementation process. 201

The determination of trace elements in selected soil profiles sampled by the Soil Survey of Scotland has continued. Work on soils from the area covered by Sheets 1, 2, 3 and 4 and part of 7 (Kirkmaiden, Whithorn, Stranraer and Wigtown) and Sheets 32 and 24 (Edinburgh and Peebles) is in progress. 101, 201

In collaboration with the Department of Soil Organic Chemistry, studies on humic and fulvic acids and their sub-fractions have continued. The samples examined were prepared from a soil, sampled at a depth of 5 to

23 cm, of the Insch Association (Insch series). Summation values of the contents of elements such as copper, iron, manganese and vanadium, in the sub-fractions of both the humic and fulvic acids show good agreement with the contents in the unseparated acids. In this soil, the percentages of these elements combined with humic and fulvic acids are 15, 1·1, 1·3 and 4·2 per cent respectively of the total amounts. In support of studies on metal-binding by soil organic matter using electron paramagnetic resonance spectroscopy, various fractions of humic and fulvic acids have been analysed for their contents of copper and other elements. 201, 203, 307

A paper describing the form of occurrence of nickel in a serpentine rock from Leslie, Aberdeenshire[61], which was mentioned in Annual Report No. 43, 1972/73, is now awaiting publication. 104, 201

The total mercury contents of 354 samples from 58 soil profiles from both cultivated and uncultivated areas have been determined. The soils were developed on a wide range of geologically different parent materials and were found to have contents ranging from <0·01 to 1·71 ppm (mean 0·13). Sixteen of the 58 profiles were uncultivated and contained iron pan horizons. In these the upper highly organic L, F and H horizons were found to contain relatively high mercury contents of up to 1 ppm. The underlying inorganic horizons had considerably less mercury although the iron pans usually showed some enrichment over the horizons immediately above or below. Among the 58 profiles two from Orkney, developed on tills derived from the Eday beds and Rousay flags, had exceptionally high mercury contents throughout the profiles. These ranged from 0·45 to 1·71 ppm. The total mercury contents of over a hundred cultivated surface soils from the Department of Soil Fertility experimental plots mentioned below and from soils on which grass sickness had occurred (Annual Report No. 44, 1973/74) have been determined and range from 0·03 to 0·37 ppm (mean 0·10). In garden soils the levels were generally higher than in cultivated agricultural soils and varied from 0·2 to 1·7 ppm. The higher values were found in vegetable-garden soils where calomel treatments had been used. 201, 205, 609

The glasshouse pot experiment on the uptake of mercury from soils mixed with an industrial chlor-alkali waste has been terminated and the results are being assessed. It would appear that, under the pot conditions used, the mercury in the pots remained largely unavailable to cocksfoot grass for 2 to 3 years, the levels in the plants being of the order of 0·05 ppm or less in the undried plants. 201, 202, 5314

Soil Status and Plant Uptake. The total number of elemental determinations carried out has remained about the same as last year. The number carried out for the Department of Soil Fertility, relating to problems associated with suspected nutritional disorders of plants or animals, has been similar for molybdenum and copper, but has increased for cobalt. 5205, 5206, 610

Analyses of surface soil and plants from the Department of Soil Fertility experimental plots covering a wide range of soil parent materials and drainage conditions have continued. Soil profile samples taken at each of the 29

experimental plots are also being examined for their total and acetic acid, ammonium acetate and EDTA extractable contents. 201, 202, 609

In collaboration with the Agricultural Development and Advisory Service of the Ministry of Agriculture, Fisheries and Food the analysis of sewage sludges, sludge-treated soils and crops from sludge-treated plot experiments has continued. The analysis of sewage sludges from four sewage treatment works sampled six times at intervals between 1964 and 1974 for total and for acetic acid, EDTA and water extractable trace elements has been completed. Three of the works have consistently produced sludges with very high contents of either chromium, nickel or zinc over the ten year period. At the fourth works, which formerly produced a sludge with a high copper content, the levels of both copper and zinc have fallen in the latest sample by a factor of at least four. In most sludges about 25 to 50 per cent of the total manganese, nickel and zinc are extractable by both acetic acid and EDTA, but the solubilities of copper and lead are lower. The total mercury contents of all the sludges from about 50 works ranged from 1·9 to 51·1 ppm (mean of 7·7). About 500 plant samples from the sludge treated plots have been analysed by a chemical concentration method for elements such as Cr, Ni, Pb and Zn. A further 250 samples remain to be analysed and when completed, an assessment of the extensive data will be carried out. 201, 202

The copper and manganese contents of about 400 plant samples from the Department of Soil Fertility field experiments on sites where the soils are deficient in one or both of these elements have been determined and about 100 samples of Sitka spruce needles have been analysed for the Peat and Forest Soils Section to obtain background information on the normal contents of the same elements in this widely grown species. 115, 202, 205, 609

Miscellaneous samples analysed have included soils (from the Department of Botany, University of Liverpool; the Institute of Occupational Health, University of London, and the Department of Biology, University of Stirling), grain and sunflower (from the N. Poushkarov Institute of Soil Science, Bulgaria), grass and Sitka spruce (from the Department of Soil Science, University of Aberdeen), animal feedstuffs (from the Animal Diseases Research Association, Edinburgh), winter wheat (from the Botany Department, University of Sheffield) and grain and straw (from the Agricultural Institute, Johnstown Castle Research Centre, Ireland). 5205, 5206

Spectrochemical Methods of Analysis

Few changes have been made in established methods for the determination of trace elements in soils, soil extracts and plant materials. A method has been developed for the preparation of mica samples, which in the past have proved difficult to grind to a powder sufficiently fine for analysis. After a preliminary grinding in an agate ball mill, a 1 to 2 g subsample is broken down by an agate ball in a 5 ml agate vial using a vibratory Spex mixer/mill. Because of the transfer of the Ilford Ltd. factory to the North of England with a consequent stoppage of supplies of their Chromatic and Long Range photographic plates, alternative sources of comparable emulsion

types have been investigated. As an alternative to the Chromatic G 30 the Eastman-Kodak SA1 plate may prove suitable. No plate entirely comparable to the Ilford Long Range appears to be available, but preliminary tests of the German Democratic Republic ORWO-WT2 plate (9 x 24 cm, obtainable from C.Z. Scientific Ltd., London) show this to be a possible alternative up to the wavelength of the rubidium line at 780·0 nm.

Arc Emission. Investigations into the application of arcs up to 20A (Annual Report No. 44, 1973/74), with the triple gas-jet apparatus described previously[19] to the analysis of soils and rocks have continued. Mixing samples with pure aluminium and carbon powders in the ratios 2:1:1 by weight has been found to be particularly effective in preventing loss of material when striking the arc and in reducing general background emission. The method seems to be especially suitable for volatile elements such as Zn which, with a 20A arc and the three jets fed with argon, can now be determined spectrographically down to 10 ppm, using the line at 334.5nm and a non-recording microphotometer. Under the same conditions, the emission of the lines Be II 313·0 and 313·1 nm appears to be unusually enhanced and Be can be readily determined down to 0·1 ppm. 205

An interference of the Zr 341·466 nm line on the Ni 341·476 nm line has been observed. 100 ppm of zirconium produce a line equivalent to about 1 ppm of nickel. In samples high in zirconium, such as some granites, errors can occur in the assessment of very low contents of nickel when either visual comparison or microphotometry is used. 205

Direct Photometry. The E789 Polychromator has been in regular use for the d.c. arc analysis of soils, plant ashes and chemical concentrates. Over 5500 samples have been analysed during the year. Daily readings of a fixed reference voltage, taken throughout the five-year period 1970-75, have shown the excellent electrical stability of the instrument. Using the Fe 319·7 nm channel as an example, over the whole period the maximum deviations on any one day from the overall average digital voltmeter reading of 3503 mV were –7 mV and +13 mV. This stability has been an important factor in permitting analytical calibration curves to be maintained unchanged over a period of years. 205, 5205

The Hilger Medium Direct Reading Spectrograph continues to be used for the analysis of soil extracts by the porous-cup solution-spark method and for plant ashes by the rotating-disk technique. 201, 202

Flame Emission. The number of samples analysed by the three-channel laboratory-built flame photometer has increased since last year, with calcium and potassium determinations each about 25000 and sodium about 16000. 5206

A Techtron AA4 spectrometer with a high-temperature nitrous-oxide: acetylene flame has continued to be used in the emission mode for the determination of aluminium in rocks and minerals after preparation of the samples by lithium metaborate fusion and dissolution in nitric acid. Aluminium was also determined in acid digests of fungi ashes on behalf of the Department of Microbiology. 207, 507

An account of the determination of the alkali metals by flame methods[20], has been published.

Atomic Absorption: Flame Techniques. The Techtron AA4 atomic absorption instrument is being fully utilized. Besides being used for the analysis of the EDTA extracts of soils for their copper, manganese and zinc contents, the number of magnesium and calcium determinations carried out has increased since last year from 10000 to 15000 and from 4500 to 6000 respectively. The work-load on the Techtron is being relieved by the transference of the magnesium determinations to the laboratory-built atomic absorption spectrometer used for the determination of cobalt in soil extracts. Modifications include interchangeable burner heads to enable magnesium to be determined using a nitrous-oxide : butane flame and cobalt using an air : butane flame. Since, however, this is a prism instrument, temperature drift effects prevent its use for the determination of elements for which the hotter nitrous-oxide : acetylene flame is required. 206

Atomic Absorption: Non-flame Techniques. The mercury content of soils and soil profiles has been determined using the cold vapour atomic absorption technique and the results have been described above. 201

The problem, mentioned in last year's Report, of obtaining representative samples of soil for mercury analysis has been investigated. Soil profile samples which were suspected of having become contaminated with this element during drying, handling or storage over a period of years within the Institute, were resampled in the field and their much lower mercury content confirmed that gross contamination had occurred. However, samples which had been immediately dried, ground and stored in glass bottles 10 years ago have remained unchanged. No significant differences in mercury content have been found between soils dried in a vacuum oven at $<30°C$ and those air-dried in the normal way at $<30°$ now that sources of free mercury have been eliminated from laboratories adjacent to the drying room. Both drying techniques show similar small losses, generally $<10\%$. Vacuum oven drying is slow and is only justified when laboratory atmospheric mercury contamination is suspected. Non-flame atomic absorption and fluorescence methods for the determination of mercury have been reviewed with particular reference to the analytical aspects[21]. 206

In collaboration with the N.E.R.C. Institute of Marine Biochemistry, Aberdeen, comparative determinations of cadmium in plant material have been carried out by atomic absorption, using the carbon-rod atomizer and the dithizone in chloroform extraction method reported last year, and by anodic stripping voltammetry, the results showing fairly good agreement. Several standard samples have also been analysed. For the Wheat Flour V2/1 and Potato Flour V-4 supplied by I.A.E.A., Vienna, the cadmium contents were similar to the reported values, but for the NBS Orchard leaf sample (No. 1571) the content (0·16 ppm) was considerably higher than the recommended value ($0·11 \pm 0·044$ ppm). The method has been used to determine the cadmium content of a variety of samples including sewage sludges. 201, 206

A silica-tube furnace for operation up to 900°C has been constructed to investigate the determination of selenium in plant materials by the selenium hydride atomic absorption method. 206

Spark-Source Mass-Spectrometry. The electrical detection systems have now been installed and tested although their analytical potentialities have not yet been investigated. Modifications have included redesigning the solenoid actuator assembly for the Auto-Spark electrode control to restore the accurate manual micrometer adjustments of electrode position available before the Auto-Spark was installed. An automatic gap control unit, which uses the amplitude of the RF spark voltage to control the spark gap width, has been constructed and is now under test. 205

A tentative method has been developed for the analysis of rocks and soils in which a chisel-shaped 50 mg sample electrode is hydraulically pressed, in a PTFE mould, from a 1 : 1 mixture of ground rock or ignited ground soil and aluminium powder (99·999%) to which 100 ppm indium (as In_2O_3) has been added as an internal standard. This electrode is sparked against a counter electrode made from pure aluminium wire and a range of exposures recorded photographically. From pen-recorded microphotometer traces of the spectra a Seidel density plate calibration curve is then prepared utilizing the naturally occurring barium isotopes whose relative abundances, and therefore relative line intensities, are known and from this curve the various line intensities are derived. The concentration (C) of a trace element (T.E.) is calculated as

$$C_{T.E.} = C_{In} \times \frac{\text{Relative intensity T.E.}}{\text{Relative intensity In}} \times F$$

where F is a factor which takes into account the relationships of the ionization potential, the isotope mass and the involatility of the trace element with respect to those of indium. By this method most trace elements can be determined semi-quantitatively without further standarization. To improve accuracy, tentative Relative Sensitivity Coefficients have been calculated for some elements (Ba, Ce, Cs, Cl, Cr, Co, Ge, La, Lu, Mo, Nb, Pb, S, Sb, Sc, Sn, Sr, Th, W, U, Y, Zn, and Zr) from data from synthetic standard samples and well-authenticated values of USGS standard rocks. For other elements (As, B, Bi, Cd, Cu, Dy, Er, Hf, Ho, I, Nd, Ni, P, Pr, Rb, Sm, Tl, V and Yb) insufficient information has so far been obtained to apply such a standardization procedure, although they have been observed and estimated in rocks and soils. While considerable work has yet to be done to establish and improve the analytical accuracy, results so far are very promising. For about 70 per cent of the elements determined a precision of ± 15 to 30 per cent has been obtained and reasonably good agreement with published values has been found for over 40 elements in USGS standard rocks and with semi-quantitative spectrographic values in soils. In this exploratory work high resolution conditions, entailing some loss in sensitivity, have been used to minimize superpositional interferences. For the majority of elements, however, sensitivity is more than adequate with detection limits $<0{\cdot}1$ ppm and for the remainder generally <1 ppm. Present indications are that lower resolution conditions will provide much lower detection limits without appreciably increasing interference. 201, 205

Investigations of plant ashes and of 8-hydroxyquinoline-tannic acid-thionalide chemical concentrates of soil extracts are in progress.
201, 202, 205

Molecular Spectrometry of Soil Constituents

Optical Absorption Spectrometry. The adsorption characteristics of soil components are crucial to the agricultural use of soils. Adsorption processes control the retention and release of fertilizer elements, pesticides, and pollutants, and also the wettability of soil surfaces. Cations and basic organic substances are adsorbed principally by organic matter and by clays, and such processes have been the subject of a continuing research programme using infrared techniques. Inorganic and organic anions are retained largely by oxides of iron and aluminium, whose surfaces have now been shown also to be accessible to infrared investigation. A very precise picture of the surface of goethite, an iron oxyhydroxide of widespread occurrence, has been deduced from observations on vibrations of surface hydroxyl groups, adsorbed carbon dioxide and adsorbed phosphate[14, 77] The mode of adsorption of other organic and inorganic anions on goethite and gibbsite is being investigated. 106, 207

Infrared spectroscopy also plays a valuable role in identifying soil minerals and characterizing their composition. In collaboration with the Department of Pedology a paper on the occurrence of a nickel-rich hydrated carbonate in a serpentinite[61] has been prepared and one on the role of iron oxides in controlling red and yellow soil colours[11] has been published. Studies on the oxidation and reduction of iron in layer silicates have been completed and the work is being prepared for publication. A review of the role of infrared spectroscopy in soil mineralogy[22] has now appeared and a survey of applications in the broader field of mineralogical chemistry[78] is awaiting publication. A simple procedure for deriving the number, symmetry class and approximate forms of the vibrations of any mineral of known structure has been described in a technical note[23]. 103, 104, 207

Collaborative studies on soil organic matter continue. Work published this year includes a criticism of mistaken interpretations of the infrared spectra of impure fulvic acid fractions[24], the recognition of small white aggregates in peat as a wax secreted by aphids[25], and the identification of acetyl groups in plant cell wall carbohydrates by infrared spectroscopy[26].
208, 304, 503

Mössbauer Studies. Mineralogical investigations of relevance to Scottish soils have continued. An account of the work with a ferroan muscovite and its implications in the assignment of sites in dioctahedral micas[79] and a note concerning the interpretation of the Mössbauer spectra of biotites[80] are awaiting publication. The studies of hornblendes and nontronites reported last year have been further extended, and in the latter, progress has been made in the elucidation of the changes that occur as a result of treatment with different reducing agents. With the aid of facilities provided by the Department of Natural Philosophy of the University of Aberdeen, iron pan samples have now been investigated in the temperature range of 4·2 to 77°K. Magnetic ordering has been observed and the implications are

currently being assessed. A study of the oxidation states of iron and of its distribution between the sites in a series of celadonites has been started and preliminary results indicate that ordering occurs to a greater extent than in either biotites or muscovities. The account of a study of the formation of iron oxides by decomposition of iron-phenolic chelates[13] has now been published. 104, 105, 201, 203, 207

In collaboration with the Department of Plant Physiology, plants have been grown in nutrient solutions containing ^{57}Fe to assess the form and distribution of iron componds in plants. No evidence was found for the presence of ferrous iron in the plants although other workers have suggested that this is the form in which it is most readily taken up. 203, 401

Electron Paramagnetic Resonance Studies. With the aid of facilities provided by the Department of Chemistry of the University of Aberdeen electron paramagnetic resonance (EPR) investigations of the nature of some transition metal complexes with soil organic materials have continued. Papers on the bonding of vanadium with humic acid[81] and the occurrence and estimation of copper-porphyrin complexes with soil humic acids[82] have been submitted for publication. EPR spectra have been obtained from several components of a fulvic acid chemically fractionated by the Department of Soil Organic Chemistry. Signals which could be assigned to copper, iron, manganese and vanadium were found, a preference of each metal for particular organic fractions being observed. The work on molybdenum complexes with humic acid reported last year has been extended and the alteration of the spectra with acid treatment has been investigated using enriched isotopes. 201, 203, 307

Studies of the organic radicals present in humic acids have continued and the variation of their EPR signals with the position in the soil profile from which the sample was extracted has been investigated. A paper concerned with the composition of soil humus[83] is awaiting publication. 203, 305, 307

3. SOIL ORGANIC CHEMISTRY

The work of the department is concerned not only with the chemical nature of soil organic matter, but also with its effects on plant growth. Investigations are carried out on the composition of individual components such as the polysaccharides, polypeptides, phenols, organic phosphates and the very stable polymers which make up a large part of the humic and fulvic acid fractions. Their origins, their association with other soil components and the factors influencing their accumulation or breakdown in the soil are also studied. The effects of humic acids and fulvic acids on plant growth are examined using whole plants, tissue cultures and isolated expanding root segments. Much of the work involves close co-operation with other departments in the Institute.

During the year the department was represented at meetings of the British Society of Soil Science, the Welsh Soils Discussion Group, the Biochemical Society and the Society for Experimental Biology.

Mr H. H. Tok, from the Institut National Polytechnique de Nancy, spent some time in the department studying methods of carbohydrate analysis.

Soil Polysaccharide

A joint paper with the Department of Microbiology describing the effects of temperature on the transformations of radioactively labelled glucose in soil during incubation[84] has been accepted for publication. As mentioned in an earlier report, polysaccharides synthesized at 20°C are deficient in xylose and arabinose relative to the indigenous soil polysaccharide. At 5°C, a temperature closer to natural field conditions, more xylose is, however, produced and this is attributed to the action of yeasts. Xylose occurs much more commonly in soil yeasts than in soil bacteria and, while the lower temperature has no effect on yeast numbers, it greatly reduces those of the bacteria. 305, 506

Since temperature effects do not explain the low arabinose production in the incubation tests, consideration has now been given to other ways in which laboratory experiments might fail to reproduce natural field conditions. For example arabinose is present in blue-green algae, which are light-dependent organisms, but laboratory incubations are usually carried out in the dark. However, when fresh soil, sampled from the surface of fallow ground, is incubated with ^{14}C glucose in the light, only traces of arabinose can be detected in the synthesized polysaccharide.

An account of an investigation with the Department of Microbiology on the decomposition of soil polysaccharide[27] and a paper describing further work using ^{14}C labelled soil polysaccharide[28] have now appeared. 305, 506

A paper reviewing recent developments in research on soil polysaccharides and carbohydrate phosphates[29] has also been published. 305, 317

A method of sugar analysis using ρ-hydroxyphenylhydrazide has now

been automated and is proving very useful for the routine measurement of sugars that have been separated as borate complexes by ion-exchange chromatography. A description of the method[85] has been submitted for publication. 305

Humic and Fulvic Acids

As part of a structural investigation on humic acids, a joint study with the Department of Spectrochemistry has been made of the effect of alkali concentration on the electron paramagnetic resonance (EPR) spectra of these soil components. In dilute alkali, for example 0·2M NaOH, solutions of humic acids from very acidic soils give spectra with a four peak hyperfine structure. Increasing the concentration of alkali to 1 or 2M results in the appearance of a second four peak spectrum and a weakening of the original peaks. These observations have been included in a paper reviewing the chemistry of soil humus[83], and the structural significance of the changes are being further considered.

A paper describing the EPR spectra of humic acid complexes with vanadium[81] has been accepted for publication and another dealing with the occurrence of copper porphyrin in humic acids[82] has been submitted. 201, 203, 305, 307

Studies on the distribution and form of metal ions in various humic and fulvic acid fractions are being continued. 201, 203, 307

Organic Matter in Podzols

As noted in last year's Report, aluminium appears to be the major metal ion associated with acid-soluble translocated humus, but it is not known whether the aluminium is translocated with the humus or by some other agent, in the latter case giving rise to accumulations of a suitable adsorbent for the illuvial humus.

Analysis of a further range of podzols and acid brown earths has provided more evidence of this trend, aluminium again being associated with the translocated humus to a much greater extent than iron. In the profiles examined at stages of podzol development before iron pan development the acid-extractable iron is greatest in the H horizon or, in these cases where a black amorphous H horizon has not yet formed, in the lower levels of the F/H horizon. An examination has also been made, in podzol profiles from the Ardersier region, of thin ochreous bands in the lower part of the profile which are typical examples of " orterde " bands. As expected, acid extracts of these zones contained higher amounts of iron than those of the surrounding soil, but in a few cases the organic matter and aluminium in the extracts were also higher. The chemical nature of the bands differs in several respects from that of the B_h humus bands. 304, 801

Podzol B_h horizons contain a high proportion of their humus in an acid-extractable form. Study of this product has indicated that easily characterized compounds such as polysaccharides, peptides and lignin represent only a small fraction of the total. Spectroscopic and titration techniques, and the synthesis of model compounds have indicated that most

of the fraction is a polymer with an aliphatic or alicyclic structure substituted by numerous carboxyl groups. 208, 303, 304, 801

Soil Organic Nitrogen, Sulphur and Phosphorus

A survey of the amino acid composition of extracted soil organic fractions has continued and, in collaboration with the Department of Soil Fertility, the occurrence and distribution of sulphur-containing amino acids is being examined. 303, 602

Most of the organic phosphate in Scottish soils is strongly sorbed and its availability to plants is low. A small part, however, can be extracted with dilute salt solutions and in this soluble form may be more accessible to attack by enzymes in the soil. The amounts of soluble organic phosphate are now being measured at intervals in a number of soils and the nature of the material is being examined. 317

Water Extractable Organic Matter

Most investigations of the effects of soil organic matter on plant growth and metabolism have made use of alkali extracts of soils and so their relevance to agricultural conditions depends on such extracts providing material representative of the substances existing in soil solution. A direct investigation of such components has now been made by extracting soil with cold water and also by pressing out the solution from moist soil. A procedure has been developed for the removal of low molecular weight non-humified organic compounds and of clay and other inorganic material, the presence of which has hitherto hindered the investigation of humified organic matter in soil solution. The concentrations of these substances found in soil solutions of agricultural soils are in the range 5 to 20 mg/l. The properties of the material are very similar to those of the fulvic acid isolated from alkali extracts. Elementary analysis, molecular weight determination and infrared spectroscopy do not allow any distinction to be made between the two types of material. Infrared spectroscopy indicates the presence of a large number of carboxyl groups. Functional group analysis confirms this and also demonstrates the presence of weakly acidic hydroxyl groups. The numbers of the latter are similar in both types of material, but the carboxyl contents of the water-extractable material and that isolated from soil solution are consistently about 20 per cent lower than that of the alkali-extracted fulvic acid from the same soil. The carboxyl content of the water-extractable material is, however, in the range found for fulvic acids and is two to three times higher than that of humic acids from the same soils.

The similarity of fulvic acid and the water-extractable material would appear to justify the use of the former in physiological experiments. This is a distinct advantage since alkali-extracted fulvic acid is easily obtainable in high yield compared with the amounts of water-extractable material.

It has previously been established that alkali-extracted fulvic acid enhances the growth of cultured tomato roots. The water-extracted material and that isolated from soil solution have now been shown to be similarly active at concentrations close to those existing in soil solution. Clearly one

outstanding question remaining is whether these water-extractable substances exert any direct effect on whole plants. 208, 309

Effects of Humic Acid on Growth and Nutrition of Wheat Seedlings

The nature and extent of the growth stimulation of seminal roots of wheat seedlings induced by humic acid preparations is still ill-defined. As regards the extent of the growth stimulation, the increased growth in a solution containing 50mg/litre humic acid varies from less than 10 per cent to more than 100 per cent, the variability being largely attributable to erratic growth of the control plants in dilute calcium chloride, which is usually considered optimal for seminal root growth. When the control plants show good root growth the improved growth in the presence of humate is proportionately less than when the control growth is below average. It has so far proved impossible to identify the reason for the occasional poor growth in calcium chloride, but growth in calcium humate is much less subject to variation. The effect of humate seems to be exerted on the morphology of the root rather than its overall growth. The roots tend to be longer and thinner and while the overall length of the root increased by an average of 32 per cent in 20 experiments, the average increase in fresh weight was only 26 per cent and in dry weight 13 per cent.

The ability of humic acid to improve plant growth under conditions of stress (e.g. solutions of high osmotic pressure or high sodium content) has been examined, but only a very slight improvement was obtained. The presence of humate had very little effect on the loss of water by transpiration. 309

To investigate the possibility that the effect of humic acid is indirectly caused by microbial breakdown products, winter wheat has been grown in nutrient solutions under axenic conditions using a thin-film isolator[86]. The plants, grown for up to 15 days in the presence of ^{14}C labelled humic acid, are similar in appearance to those grown in the presence of microbes and there is again an increase in fresh and dry weights of both roots and shoots compared with those of the controls. The radioactivity is taken up by the wheat roots, but whether humic acid is taken up in an unaltered form is not yet known. Most of the radioactivity remains associated with the roots and little is translocated to the shoots even after 15 days. Only 30 to 40 per cent of the radioactivity taken up by the roots is associated with the cell walls and a large proportion might thus be available for involvement in metabolic processes within the cells as already shown during cell elongation in the roots of *Pisum sativum*. 311, 5613

An investigation has also been started on the effect of humic acid on the germination of wheat seeds under axenic conditions. Soaking seeds in humic acid solutions for up to 24 hours does not affect their rate of germination. When seeds soaked in humic acid are transferred to nutrient solutions the fresh weight of the developing seedlings is increased by up to 15 per cent relative to those from seeds soaked in water prior to germination. Radioactivity from labelled humic acid is taken up by the seeds and on subsequent germination the level of activity found in the shoot is similar to that found in the root. 311, 5613

Effects of Humic Acid on Cell Elongation in Pea Roots

Work on changes in the protein complement of cell walls during cell elongation in excised pea root segments has continued.

During cell elongation ^{14}C- and ^{35}S-labelled 2-thiouracil are incorporated into RNA, where they replace uracil, and into a non-nucleotide fraction of the cell wall from which they cannot be completely removed using nucleic acid and protein extractants. Acid hydrolysis of the residual fraction yields labelled 2-thiouracil and unlabelled amino acids. Experiments using labelled 2-thiouracil, orotic acid, leucine, proline and hydroxyproline support the hypothesis (Annual Report No. 44, 1973/74) that 2-thiouracil, and similar thiol-containing analogues of nucleotides and amino acids, enhance the growth rate of segments by becoming attached to cysteine in the cell-wall proteins. Thus an increase in wall rigidity, brought about by the formation of disulphide bridges between cysteine residues in structural wall proteins, is delayed or prevented[30]. Furthermore it appears that the structural wall proteins which influence wall rigidity are also rich in hydroxyproline, an imino acid which itself can influence wall rigidity (Annual Report No. 43, 1972/73).

The ultimate aim of investigating basic mechanisms controlling cell elongation is to provide information to aid the interpretation of the action of humic acids on plant growth. This objective has also been pursued by joint experiments with the Department of Plant Physiology using phenolic substances that can be derived from soil organic matter by chemical hydrolysis[87]. Some phenolic compounds such as cinnamic, ferulic, chlorogenic and caffeic acids enhance cell elongation in excised pea root segments. ^{14}C-labelled cinnamic acid is continuously incorporated into the proteins of the cell walls and it appears that the radioactivity is transferred to the cell walls *via* the cytoplasm. The available evidence suggests that externally supplied phenolic substances inhibit the formation of cross-linkages between those phenolic structures (such as diferulic acid) which influence cell expansion. 311, 402

Fungal Pigments

The brown fungal pigments from *Stachybotrys atra, Epicoccum nigrum* and *Aspergillus niger* are biologically active in stimulating the development of invertase activity in disks of beetroot tissue during ageing under axenic conditions. Gel filtration studies show that most of the pigments from *S. atra* and *E. nigrum* comprises material of molecular weight, MW, less than 2500 and is eluted from the gel column as a single peak. In contrast aspergillin derived from *A. niger* is eluted from a gel column as three substances of different colours, *viz.* a grey substance (MW greater than 50000), a brown substance (MW 2000 to 5000) having infrared and visible spectra similar to humic acid, and a yellow-green substance (MW *ca*500). The brown and yellow-green components stimulate invertase development in beet disks, but the grey component is without effect. Extraction of aspergillin from *A. niger* grown on ^{14}C-labelled sucrose yields a product in which all three aspergillin components are labelled. All are taken up by beet disks showing that the inability of the grey component to stimulate the

development of invertase activity is not due to the inability of the beet tissue to incorporate it. The nature and composition of the yellow-green component is now under investigation. 301

A joint study with the Department of Microbiology on the enzymes present in the colourless exudate of sclerotia from *Sclerotinia sclerotiorum* has shown that the exudate will bring about the oxidation of gallic acid, guaiacol, resorcinol, catechol, protocatechuic acid, pyrogallol and phloroglucinol. The oxidation of all these substrates is prevented in the presence of sodium azide and dazomet, an effect reversed by adding excess of copper as copper sulphate. Dazomet and sodium azide will not, however, prevent the oxidation of these phenolic substances in the presence of sodium hydroxide. The kinetics of the phenolase activity from the exudate have been studied in some detail using guaiacol and L-dopa as substrates. The phenolase is similar to that obtained from other fungi and higher plants and requires copper. The requirement of this enzyme in the darkening processes involved in the walls of the sclerotia remains in doubt, however, because the addition of sodium azide or dazomet to the newly formed exudate of sclerotia does not prevent the subsequent darkening of these resting bodies. 301, 508

Effects of Humic Acid on Ion Uptake by Beetroot Disks

An investigation mentioned in last year's Report on the differential effect of humic acid on the absorption of several cations, including sodium, barium and zinc[88], has now been completed and a paper submitted for publication. 311, 5613

4. PLANT PHYSIOLOGY

The work of the department continues to be concerned with ion flux in plants in relation to mineral nutrition.

Dr P. C. DeKock attended the XII International Congress of Botany in Leningrad in July. Dr A. E. S. Macklon attended the Society of Experimental Biology Symposium on Calcium in Biological Systems at the Royal Holloway College, University of London in September.

Calcium

Potatoes, cv. Majestic, from soil pH plots (4·5 to 7·5) at the Craibstone Experimental Farm were used in calcium flux experiments. Cores were struck from the centre and the fifteen consecutive pieces from heel to rose ends were analysed for various elements and constituents. Equations were calculated for the distribution and ratios of the elements. pH was shown to have little effect on the distribution of major elements, apart from calcium which increased with increasing pH, but the ratios of monovalent to divalent cations and of phosphorus to iron were both at a maximum at pH 6 and decreased towards either end of the pH range. This work has been prepared for publication. A paper on the effect of calcium on the potato sprout[89] has also been accepted for publication. 402

In collaboration with the Peat and Forest Soils Section, blossom-end-rot (B.E.R.) of tomatoes grown in bags of peat has been further investigated, using nitrate, ammonium nitrate and urea as nitrogen sources in the liquid feed. Incidence of B.E.R. was high with ammonium nitrogen in the feed; with nitrate nitrogen incidence was low. Studies on the composition of the fruit and on the phenolic changes have continued. 114, 402

Iron

A similar series of potatoes was examined for the activities of peroxidases and catalase in consecutive pieces cut from cores struck from heel to rose ends as previously. Equations of activity were then computed. In all cases catalase showed a hyperbolic curve of activity, being greatest in the centre of the tuber and declining towards either extremity. At higher pH values peroxidase was in inverse relationship to catalase, but at lower pH levels the activity of peroxidase showed a linear relationship from heel to rose ends. However, the ratio of peroxidase to catalase was at a minimum in the tuber at pH 6, in agreement with the ratios of the elements previously examined. This work has been prepared for publication.

By means of Mössbauer spectrometry the forms of iron in plants can be studied using the stable isotope ^{57}Fe. The so-called '100% double' cultivar of *Matthiola incana* has been chosen as the experimental plant because the seedlings segregate into two groups, one of which remains green at all temperatures, while the other shows chlorosis at temperatures below 10°C. Hence the effects of temperature on the metabolism of the two types of plant can be compared. Preliminary experiments have shown no evidence of any iron in the ferrous form and the nature of the ferric form in the

plant is being further investigated. This work is being done in collaboration with the Department of Spectrochemistry. 401

Earlier work on the effects of the salicylic acid chelate of iron on the growth of Lemna[31] has been published and also work on the effects of various chelating agents and phenols on the growth of roots[87].

Ion Flux Studies

The fluxes of Mg^{2+} in cells of onion root segments have now been studied. As with Ca^{2+}, the main difficulty lay in assessing the partitioning of the magnesium content of the tissue between the cell compartments, and in determining the proportion of magnesium that was chemically active. Mg^{2+} concentrations in the vacuole could be estimated only as lying between wide limits (1·3 to 14·3 $\mu eq.ml^{-1}$), but whatever the concentration within this range, it was concluded that Mg^{2+} was passively distributed across the tonoplast membrane bounding the vacuole. It appears that Mg^{2+}, like Ca^{2+}, enters the cytoplasm of the root cells passively down a diffusion gradient, and entry is limited by an efflux pump at the outer membrane (plasmalemma). Magnesium reaching the conducting tissue of the root segment is transported almost exclusively in the basipetal direction.

Accounts[32, 33] of flux studies with K^+, Na^+ and Cl^- and with Ca^{2+} have now appeared. A paper[90] describing the findings for Mg^{2+} has been accepted for publication. 407

Autoradiographs of plant roots that have been allowed to absorb radioactive isotopes of major nutrient ions generally show that the isotope is present throughout the root, but frequently with the highest concentration in the root tip. This effect has been demonstrated for ^{45}Ca and ^{28}Mg in onion roots. However, for ^{22}Na and ^{36}Cl no such concentration at the root tips is evident. The autoradiographs suggest rather that the tips have a lower content of these ions than the older parts of the root. ^{42}K shows an even distribution between the tip and the subapical part of the root. These finding are consistent with the results of gross chemical analysis of root tips and subapical root segments. However, for most ions studied, a difference in concentration between root tip and subapical parts of the root is, in a sense, illusory. Bearing in mind that in the root tip the bulk of the cells are non-vacuolated, the gross chemical analyses reflect largely the cytoplasmic contents of the ions under study. Comparison with cytoplasmic content values for subapical root tissue, obtained indirectly by compartmental analysis, [32, 33, 90] reveals that, for the most part, ion concentrations in the tip cytoplasm are very similar to those in the cytoplasm of fully differentiated cells. This observation supports the view that compartmental analysis yields relatively accurate estimates of cytoplasm content, a conclusion that has been questioned in the past. Of the ions studied, only Mg^{2+} does not fit the general pattern. It appears that for this ion there is a true concentration effect in the root tip cytoplasm, where the magnesium content appears to be an order of magnitude higher than that estimated in the cytoplasm of fully vacuolated cells. However, this discrepancy may occur because gross chemical analysis of the root tip does not discriminate

between ionized and bound magnesium. The latter may be particularly high in the root tip. 407, 613

One of the accounts of work on membrane permeability and related physiology in yam tubers[34], in collaboration with the School of Agriculture, Aberdeen, has been published; the other[91] is still in press. 407

Metabolic Control of Ion Uptake Mechanisms in Wheat Leaves

Leaf cells, like root cells, require and at the same time provide a sink for nutrient ions entering the plant from the soil. However, in addition to the uptake mechanisms common to plant cells generally, leaf cells are able to utilize photochemical energy directly, and so ion uptake may be stimulated in the light. A light-enhanced uptake of chloride has been demonstrated both in whole water-infiltrated laminae and in 1·5 mm leaf slices from wheat seedlings. In the dark, the slower uptake by whole laminae relative to chopped tissue was thought to be due to cuticular resistance to solute penetration, which was overcome in the light by stomatal opening. The absorption mechanism itself was not impaired by vacuum infiltration. Attempts to relate light-enhanced uptake to photosynthesis revealed that the high rates of oxygen evolution and CO_2 fixation characteristic of photosynthesizing wheat leaves were almost completely suppressed by vacuum infiltration. However, slicing the leaves to give 1·5 mm segments also reduced photosynthetic gas exchange considerably. Respiration rates were unaffected. It appears that both vacuum infiltration and slicing of leaves are acceptable techniques for ion uptake experiments, but are less appropriate for photosynthetic studies. Accounts of this work[35, 36] have now been published.

Chloride uptake by seedling wheat leaf tissue has been further studied, using metabolic inhibitors and anaerobiosis to elucidate the energy pathways involved. The results indicate that the uptake of Cl^-, supported in the dark by oxidative phosphorylation, is enhanced in the light by cyclic and non-cyclic electron flow energy. Uptake is not apparently obligatorily linked to any one energetic pathway and there may be switching from one energy source to another. A paper describing these results[92] has been accepted for publication. Work with inhibitors has now been extended to the study of phosphate, sodium and potassium. 407

5. MICROBIOLOGY

The work of the department is concerned with the study of the major groups of soil micro-organisms, bacteria, fungi, actinomycetes and protozoa, their relationships to the healthy development of crops and their role in the breakdown of organic matter in soil, including peat.

Progess in the on-going projects is detailed below. Staffing difficulties have delayed the start of two of the approved projects and curtailed work on others. It is hoped to remedy this in the coming year. The allocation of two additional rooms to the department has eased the shortage of laboratory accommodation.

During the year Dr J. F. Darbyshire visited the Institut für den Wissenschaftlichen Film, Göttingen, West Germany, to study specialized techniques for micro-cinephotography. He was elected to the Committee of the Ecology Group of the Society for General Microbiology and was invited to give a lecture on the Rhizosphere to the Society of Applied Bacteriology. Members of the department attended scientific meetings and symposia at the University of East Anglia, Norwich, the University of York and the University of Aberdeen, and visits were made to organizations with allied interests.

In August Dr John L. Neal of the Canadian Department of Agriculture Research Station, Lethbridge, Alberta, joined the department for a year to take part in investigations on plant roots and micro-organisms.

Interrelationships of Plant Roots and Micro-organisms

Investigations of the microbial populations and the nitrogen status of the rhizosphere soil around the roots of spring barley grown in fields which have borne several consecutive barley crops have continued, with the collaboration of the Department of Soil Fertility and the Division of Plant Pathology of the North of Scotland College of Agriculture. Special attention has been paid to the microbial antagonists of *Gaeumannomyces graminis*, the fungus responsible for take-all disease of cereals. Preliminary results for barley suggest that antagonists are more numerous on the roots of stubble than on the roots of the growing crop. Parallel experiments in the glasshouse, using either undisturbed soil cores or sieved soil from the same fields and treatments involving varying proportions of ammonium and nitrate nitrogen, have shown that it is possible to manipulate the nitrogen status of the rhizosphere throughout the life of the barley crop. These experiments are still in progress, but there are indications that the incidence of take-all disease in barley can be affected by changing the nitrogen status of the rhizosphere. As in the previous year, there was a severe reduction in the active population of protozoa and the total population of bacteria in the rhizosphere immediately after harvest. The bacterial and protozoan populations in the barley rhizosphere soil were determined by the micro-diluter method[37], which has been modified for use with microbial antagonists.

504, 603

Examination of the isolates antagonistic to *G. graminis* in the above experiments showed that they were non-lytic to the hyphal walls of the fungus. Hyphal walls of *G. graminis* were also added to the microwells of microtitre plates of the untreated samples of spring barley from the above glasshouse experiments. The contents of the microwells, after incubation, were microscopically examined and isolates giving a positive lytic effect on the walls of *G. graminis* have been obtained and are being studied further. 501, 504

Investigation of the lytic properties of micro-organisms from the washed roots of the barley cultivar Ymer grown in the glasshouse on sieved soil of the Boyndie Association showed that a number of the isolates which lysed yeast cell walls produced varying degrees of lysis of the hyphal walls of *G. graminis*. The partially lysed material remaining on completion of the experiment was examined by the Department of Spectrochemistry. The results showed that the lytic attack on the walls by actinomycetes differed markedly from that of the non-fruiting myxobacteria. 208, 501

Survey of Protozoa in Scottish Soils

Further samples from agricultural soils, collected in conjunction with the Soil Survey of Scotland, have been examined. An unusual amoeba has been isolated from several soil associations in the North of Scotland. This amoeba has a flagellate phase in its life history but, unlike the common soil amoebae of the genus *Naegleria*, it can reproduce in the flagellate phase. Electron and conventional microscope studies of this new amoebal isolate have been made in collaboration with the Curator, N.E.R.C. Culture Collection of Algae and Protozoa, Cambridge. Although it has some similarities to *Adelphamoeba* and *Tetramitus* spp., its taxonomic affinities are uncertain. Preliminary tests with mouse embryo tissue culture cells, in collaboration with the Department of Bacteriology, Aberdeen University Medical School, suggest that it is non-pathogenic to mice, unlike some species of *Naegleria*. A joint paper describing this new amoebal isolate has been prepared for publication. 510

Systematics of Soil Flagellates

Reliable indentification of soil protozoa is an essential prerequisite to ecological studies of these species. Many systematic descriptions of the common soil flagellates are based on 19th or early 20th century studies. A detailed study of one of the commonest soil flagellates, *Heteromita* sp., which is easily confused with *Bodo* spp., has shown that modern electron and conventional microscopy can be invaluable in systematic problems. Transmission electron microscopy has been used to demonstrate 3 new organelles in *Heteromita* sp., one similar to microbodies found in algae, another similar to the kinetocysts of pseudoheliozoans, but the third does not closely resemble any protozoan structure so far described. Time lapse photography and cinemicrophotography have been used to analyse the movement, reproduction and nutrition of *Heteromita* sp. A series of electron-micrographs of this flagellate was exhibited at a local meeting of electron microscopy held in the Zoology Department, Aberdeen University, in

February and a description of this flagellate is being prepared for publication in collaboration with the British Museum (Natural History). 510

The Growth of Protozoan Populations in Liquid Media and Soil

A paper dealing with the growth of the ciliate *Colpoda steini* with the nitrogen-fixing bacterium *Azotobacter chroococcum* in large batch cultures of liquid media[93] has been submitted for publication.

The effect of water suctions on the growth of *C. steini* and *A. chroococcum* has been studied. Pots containing presterilized soil samples were inoculated with either *Azotobacter* rods or a mixed culture of *Azotobacter* and active trophozoites of the ciliate, and either saturated with water or subjected to definite pF values during incubation. At pF 2·7 the *Colpoda* population decreased after inoculation while at smaller pF values the ciliate populations increased and the duration of the growth period became greater as the degree of suction was reduced. The largest ciliate populations were obtained in saturated soil samples 28 and 35 days after inoculation.

A review of microenvironmental factors influencing protozoan growth in soils[58] has been published. 502, 505

Soil Fungi

Ultrastructure. Certain soil fungi possess spine-like projections on their spores and on the membranes associated with the spore-bearing structures. The use of a combination of techniques to identify the components in spines from various species of Mucorales, and to reveal their distribution, is described in a paper[58] accepted for publication. Investigation by these techniques, which included electron probe microanalysis, X-ray powder diffraction and infrared spectroscopy, showed that the spines consisted largely of the dihydrate of calcium oxalate (weddelite). The morphological features of the fungi were revealed by scanning electron microscopy. 109, 507

A paper on the ultrastructural features of the apothecium of *Sclerotinia sclerotiorum* (Lib) de Bary[39], a soil-borne plant pathogen, has appeared. 507

Surfaces of healthy narcissus leaves and of others colonized by mites and infected by *Sclerotinia narcissicola* were examined for the Division of Plant Pathology of the North of Scotland College of Agriculture. Scanning electron micrographs showing the presence or absence of wax on these leaves were exhibited by the College in a section on bulb diseases at the Open Day for Growers at Craibstone in August. Enlarged photographs of fungal spores examined in a scanning electron microscope were exhibited at a meeting on electron microscopy in the Zoology Department, University of Aberdeen, in February. 507

Sclerotia of Plant Pathogens. A paper on the fungicidal action of Dazomet, a soil fumigant, on sclerotia of *S. sclerotiorum*[40] has been published. During July and August visits were made to nine farms in Kincardineshire on which a total of 129 ha of vining peas were grown, with the object of assessing the distribution of disease in these crops. There was little evidence of diseased plants on five of the farms (70·8 ha) visited towards the end

of July, but towards the second week of August definite signs were present on three of these farms, although the crop was only slightly damaged.

The pathogen was found in peas on the remaining four farms (58·3 ha) during the first week of August, and on two of these (17·8 ha) damage was quite severe. Suitable material has been collected for further laboratory investigations. 508

Advice on a possible method for improving the germination rate of *S. sclerotiorum* sclerotia for experimentation was given on request to the Plant Pathologist at A.D.A.S., Trawsgoed, Aberystwyth, where field control methods are being examined. Sclerotia were induced to germinate in an illuminated incubator with timed cycling of lights and temperature. Saucer-shaped fruiting bodies (apothecia) are formed, 5-10 mm in diameter and from these are discharged vast numbers of ascospores. The photographic plate shown on the next page typifies a spore cloud emanating from a fruit body. Various isolates of *S. sclerotiorum* from different agricultural crops and weeds were forwarded to the Botany Department, Brandon University, Manitoba, Canada, where comparative pathogenicity tests are being conducted. 508

The study of the enzymes present in the colourless drops exuded by sclerotia has continued, in collaboration with the Department of Soil Organic Chemistry. 301, 508

Soil Organic Matter

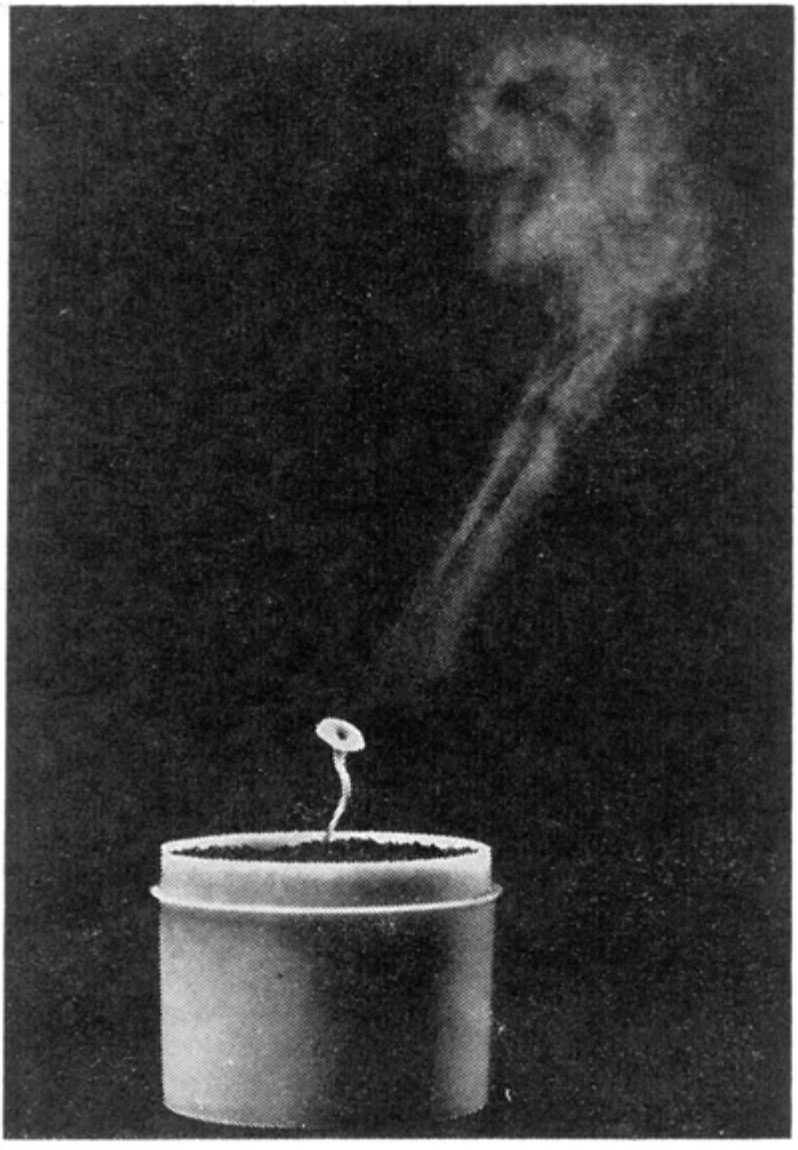
Microbial Decomposition and Synthesis. A paper on the study of the microbial decomposition of soil polysaccharide[27], in collaboration with the Department of Soil Organic Chemistry, has appeared, and results of further work[28], presented at the International Colloquium on Biodegradation and Humification held in Nancy, France, has also been published. 305, 506

An account of the investigations described in Annual Report No. 44 1973/74 on the microbial synthesis of polysaccharides in soil[84], carried out in collaboration with the Department of Soil Organic Chemistry, has been accepted for publication. 305, 506

Work on the microbial decomposition of barley roots suggests that decomposition of the cortex and epidermis is an initial stage, probably in progress while the plant is still alive. Further understanding of microbial decomposition of plant roots requires the use of modern techniques suitable for undisturbed soil. An account of the work done so far[41] has been published. 501, 504

Microbiology of Peat

Work on the study of the bacterial flora of the basin peat at the Lyne of Skene has continued. The microdiluter technique[37] has been modified and a growth medium suitable for estimating the number of anaerobic micro-organisms in the peat has been found. An incubation chamber for the microtitre plates has been devised in which the atmosphere can be not only controlled, but also monitored by gas chromatography. The chamber is now under test for estimating the anaerobic populations of peat samples and evaluating their activity and the nature of the gases they produce. 108, 503



Spore cloud discharged from apothecium of *S. sclerotiorum*. Photographed using electronic flash, duration approximately one thousandth of a second.

A detailed account of the aerobic bacterial population of the basin peat at the Lyne of Skene and the correlations between population numbers and physical and chemical parameters[94] has been submitted for publication. 116, 503

A paper on the occurrence of wax fibres secreted by the aphid *Colopha compressa*[25] has been published. 208, 503

Production of Cell Material and Microbial By-products

In addition to batch fermentation, continuous culture methods have been used for the production of bacterial and fungal cell material for investigations within the department and in other departments of the Institute. When the lytic myxobacterium *Cytophaga johnsonii* was grown by continuous culture individual cells were more uniform but less numerous than when the organism was grown in batch culture. Collection of the microbial material grown under continuous cultivation has been facilitated by the use of a more convenient cooling system. 502

6. SOIL FERTILITY

The research programme continues to be directed towards improvement of fertilizer usage and crop production through better understanding of the influences of pedological factors, soil properties, husbandry practices and environmental conditions. Complementary field, pot culture and laboratory studies have, therefore, been continued and extended in three main areas. These are (a) the nutrient relationships, properties and productivity of selected contrasting soil series mapped by the Soil Survey of Scotland; (b) the effects of lime, trace element amendments and fertilizers, including form, rate, frequency, time and method of application, on the growth, development and nutrient content of the main agricultural crops; (c) the principles and factors which affect the selection, calibration and practical usefulness of laboratory methods for evaluating the lime and nutrient status of soils as a guide to practical recommendations.

Consultative activities, especially advisory soil testing in collaboration with the North of Scotland College of Agriculture and talks at meetings of advisers and farmers, continue to provide essential reciprocal links between research and practice. Collaboration has also been maintained with other research organisations, especially the Rowett Institute, and with several technical committees. Under the latter head come the Soil Science Committee of the Arable Crops and Forage Board of the Joint Consultative Organisation for Research and Development in Agriculture and Food; a Working Group on Soil Fertility and Vegetable Crop Nutrition set up by the Field Vegetables Committee of the Horticultural Board of the same Organisation; the Scottish Standing Committee for the Calculation of the Residual Values of Fertilizers and Feeding Stuffs; a Working Group convened by the Department of Agriculture and Fisheries for Scotland to prepare Codes of Practice for Application of Lime, Fertilizers and Livestock Manures for Arable Crops and Grassland; and the three Area Drainage Liaison Panels set up by the Colleges of Agriculture under the auspices of the Scottish Agricultural Field Drainage Group. The department was also represented at a Conference on Agriculture and Water Quality, organized by the Agricultural Research Council and the Agricultural Development and Advisory Service, in the School of Agriculture of the University of Nottingham; at a meeting in Edinburgh organized by the Scottish Agricultural Development Council to discuss Prospects for Direct Drilling and Reduced Cultivations under Scottish Conditions; and at a Symposium in London on Copper in Farming, organized by the Copper Development Association, where a paper[95], mentioned in the trace elements section below, was presented.

During a study tour in the Netherlands in September, Dr P. W. Dyson attended the VIth Triennial Conference of the European Association for Potato Research at Wageningen and visited a number of research centres. Mr A. H. Knight attended the VIth Annual Meeting of the European Society for Nuclear Research in Agriculture, held in September at Caderache, France.

Professor J. A. Robertson, Department of Soil Science, University of Alberta, Edmonton, Canada, completed a stay of nearly a year in the department, during which he studied residual effects of phosphate in soils.

Crop Responses to Fertilizers

The results of two field experiments with barley, testing comparable commercial granular and liquid NPK fertilizers, applied at rates supplying up to 90 kg N, 40 kg P and 75 kg K / ha, have shown no difference between them when broadcast and only small differences when they were placed in the same position relative to the seed. Even at the highest rate there was no evidence of any harmful effects on brairding or early growth from combine-drilling the granular fertilizer, but some of the plants in the plots where liquid was combine-drilled, especially at the highest rate, had a yellowish colour for a few days after brairding. As expected, combine-drilling the granular fertilizer was slightly superior to broadcasting, especially at sub-optimum rates. Combine-drilling the liquid fertilizer produced yields similar to those obtained by broadcasting, and was slightly inferior to combine-drilling the granular form. When placed 5 cm to the side of, and at the same depth as, the seed, however, there was no difference between the two forms, and the yield was equal to that from combine-drilling the granular materials. Further comparisons of methods of applying granular and liquid fertilizers are in progress. 608, 5701, 5703

An experiment with barley has been started to investigate the effects of three methods of cultivation, normal ploughing, chisel ploughing and no ploughing, on the need for and response to phosphate. Appropriate herbicides will be used to control weeds, especially with the no-ploughing treatment. Experiments, mentioned in last year's Report, with the new barley varieties Maris Mink and Universe, suggest that their needs for, and responses to, nitrogen, phosphate and potassium are similar to those of the other varieties commonly grown. With adequate nitrogen, yields of 7 t/ha of barley grain (85% dry matter) have been obtained in 1973 and 1974 in some of the experiments with the varieties Golden Promise and Maris Mink. This is about 1 t/ha better than is normally attained, even under very good farming practice. 603, 608, 5206, 5701, 5703

In three experiments with swedish turnips no yield difference was found between potassium chloride and potassium sulphate. Since ammonium nitrate and ammonium phosphate are now the main sources of nitrogen and phosphate in many commercial fertilizers, it is desirable to check whether earlier findings using materials based on ammonium sulphate and superphosphate still apply. Experiments have, therefore, been carried out on swedes to compare broadcast applications of ammonium nitrate and current NPK fertilizers with dressings placed in bands 5 cm directly below the seed. 603, 608, 5206, 5701, 5703

Field experiments on arable crops and grassland continue to be carried out to assess needs for applying major nutrients under different soil conditions, and samples of the produce continue to be analysed to determine nutrient contents and uptakes. 603, 608, 5206, 5701, 5703

Crop Growth and Development

Detailed studies on the effects of fertilizers, environmental factors and husbandry practices on the progressive accumulation of dry matter and nutrients by barley and swedes or potatoes have been continued at four contrasting field centres, equipped to measure soil and air temperatures, rainfall, humidity, wind speed and soil moisture. Sufficient continuity of treatments has been maintained to enable seasonal differences to be monitored, and at three of the sites the effects of sowing swedes in the first compared with the third week in May have been investigated. Early sowing substantially increased root growth rate in the period of most rapid growth, from late July to mid-September, but subsequently the later sown crop grew more rapidly. A more complete analysis of the effects of plant nutrients on the growth of swede roots has now been made. With optimum nitrogen dressings, early root growth was quickly maximized and sufficient leaf area was maintained to utilize the limited radiation in the autumn. With above-optimum nitrogen, there was a substantial reduction in early growth, and the more rapid growth later in the season was insufficient to compensate for this retardation. Inadequate dressings of phosphate decreased root growth rate from the start of root swelling to the end of September and the differences in root weight at this time were maintained until the end of the growing season. There was no evidence that unnecessarily large phosphate application had any adverse effect at any stage of growth. With optimum dressings of potassium, root growth rate relative to deficient crops was increased in the early and late stages of the growth period. There was some evidence that above-optimum dressings of potassium decreased yield by reducing root growth rate at the end of the season. 607

Studies on the growth of barley have been intensified by the addition of an extra experiment in which samples were taken twice a week to measure various growth parameters and the uptake and form of nitrogen in the plants. The preliminary results support the suggestion made in last year's Report that grain yield is determined before ear emergence. 606, 607

Two accounts of work described previously (Annual Report No. 43, 1972/73), on the effects of calcium on sprout growth of different potato cultivars[42, 43] have appeared and a joint paper with the Department of Plant Physiology[59] is awaiting publication. 402, 607, 5206

Chemical Composition of Plants

As indicated in last year's Report, relationships between dry matter yield and the so-called excess base content of leaves of young plants, measured as C–A, the difference between total cations and inorganic anions, have been found to be very variable. The correlations for different crops and varieties, in pot cultures as well as field experiments, seldom exceed about 0·6, and C–A does not appear to be an important factor governing yield under normal field conditions. To clarify the significance and interrelationships of the various factors, especially nitrogen uptake and stage of growth, which affect C–A, measurements have been made throughout the growth period on barley samples from a field experiment. Since the complementary studies on crop growth and development, summarized above, have indicated

that a major factor determining final grain yield is the nitrogen uptake before ear emergence, samples were taken at intervals of three to four days up to this stage. Five levels of nitrogen, ranging from 0 to 100 kg/ha N, were applied, but during the very early growth there was very little effect on the nitrogen content of the leaves. Subsequently, the differences increased, and reached a maximum at about 47 days after sowing, when the 100 kg/ha N rate gave a leaf nitrogen content nearly double that of the no-nitrogen treatment. Beyond this stage the relative differences decreased and the absolute contents fell as ear emergence approached. In keeping with the known relationships between nitrate reduction and organic acid synthesis, the pattern of change in C–A followed the nitrogen changes very closely. The results indicate that physiological age and time of sampling are very critical factors in these relationships, and quite small differences in these two factors probably account for much of the variability in the previous relationships between yield and C–A. Determinations of the forms of nitrogen in the samples remain to be completed, but it seems likely that relationships between yield and C–A may well derive largely from corresponding changes in total nitrogen uptake. Such changes must clearly be taken fully into account before drawing any conclusions about apparent influences of C–A. 606, 5206

Trace Elements

Two experiments on grassland, started in 1973, have been continued to assess possible needs for supplementary dressings of trace elements when removal in herbage cut three times per year is increased by high rates of nitrogen. 609, 5205, 5206

Results of experimental work on copper deficient soils during the past twenty years were illustrated in a paper[95] presented at a Symposium, mentioned earlier, on Copper in Farming. Copper applications increased the yield of grain from spring-sown oats and barley, but produced little or no increase in the yields of potatoes, swedish turnips and mixed herbage from temporary leys. On these deficient soils, all the crops had low copper contents, but these were normally increased by copper treatment, to an extent depending on the crop and on the method and rate of application. Residues of copper dressings seem at least as efficient as fresh treatments in remedying deficiency in cereals and in raising the copper content in crops and herbage. For example, dressings of copper sulphate supplying 1·4 to 28·5 kg/ha Cu have been very effective for 10 to 18 years after application. The results of an experiment on a newly established temporary ley, however, show that effects on the copper content of herbage depend on the amount of nitrogen applied. In this experiment dressings of 0, 100 and 200 kg/ha N were applied annually to plots treated with 0, 5·7 and 28·5 kg/ha Cu as copper sulphate, and the herbage was cut three times per year, at the silage growth stage, one third of the annual nitrogen being applied for each cut. Copper treatment increased the content in the herbage both in the absence and presence of applied nitrogen. Without applied copper, however, the dilution effect of the increased yield produced by nitrogen, especially the higher rate, decreased the copper content, the effect being

much less in the first than in the second and third years. With 200 kg/ha N and no copper, the mean content in the mixed herbage fell from 4·5 ppm Cu in the first year to 2·7 in the third. Where copper was applied, there was a consistent trend for nitrogen to raise the content. For example, with 200 kg/ha N the mean content produced by the 5·7 and 28·5 kg/ha Cu treatments were 7·6 and 8·3 ppm Cu, respectively, compared with 7·1 for both treatments where no nitrogen was applied. Ryegrass and clover, the two main species in the sward, showed the same trends as the mixed herbage, including the positive interaction between nitrogen and copper. This effect of nitrogen in increasing the copper content of grasses on soils with an adequate copper supply, both naturally and as a result of treatment, has also been found in other experiments. When little or no nitrogen is applied to leys, the increase in copper content of the grasses, mainly ryegrass, from normal dressings of about 5 to 30 kg/ha Cu are unlikely to exceed 2 ppm, even on deficient soils, and are usually less than 1 ppm. The positive interaction between applied copper and high rates of nitrogen may, therefore, be useful and deserves further investigation. The copper content of clover, on the other hand, can be more than doubled by normal copper treatments of deficient soils, but the corresponding increases for potato tubers, turnip roots and cereal grain and straw are usually less than 50 per cent. 609, 5205

Nitrogen

To obtain more detailed information about the movement and fate of applied nitrogen under field conditions, preliminary comparisons of cropped and uncropped plots have been carried out at three centres representing contrasting soil series, partly to establish suitable sampling procedures. Each experiment comprised four plots, each of 90 m^2, two of which were cropped with barley and two kept fallow, with one member of each pair receiving 100 kg/ha N as nitrochalk and the other no nitrogen. To measure yield and nitrogen uptake, 1 m^2 portions of the cropped plots were harvested at monthly intervals. Immediately after each harvest, soil samples representing depths of 0 to 12, 13 to 25 and 26 to 36 cm were taken from the harvested portions, and from corresponding sections of the uncropped plots, for estimations of nitrate and ammonium nitrogen. Since core sampling proved unsuitable, the samples were obtained by excavating small sections within the areas concerned. Depending on the outcome of the results, further work on these lines is envisaged. 603, 608

Progress has also been made in rationalizing relationships between laboratory measurements of soil nitrogen and the yield and nitrogen uptake of oats grown with no added nitrogen in pot cultures. In two out of three seasons, measurements of mineralizable nitrogen alone, for example by incubation or mild chemical treatments, gave good correlations of about 0·8 with the crop data, and the relationships were not significantly improved by taking account also of the initial inorganic nitrogen contents of the soils. In the other season, however, the reverse was true, and to ensure the best assessment of nitrogen status both types of measurement should be considered. 603

In collaboration with the Department of Microbiology, further measurements of nitrate and ammonium nitrogen have been made on soil samples from around the roots of barley plants, grown in the field and in pot cultures, in relation to the incidence of take-all disease. 504, 603

Phosphorus

An appraisal of the practical implications of soil phosphorus studies was prepared for the Soil Science Committee of the Arable Crops and Forage Board of the Joint Consultative Organisation for Research and Development in Agriculture and Food. 601, 602, 605, 608

Detailed characterization of the quantity-intensity relationships of major soil series is one important area where further work is needed. Laboratory procedures for preparing the necessary adsorption and desorption isotherms are accordingly being studied. The prime requirement is to establish phosphate enrichment and depletion procedures which give results compatible with equilibria attained under field conditions. Reference isotherms have, therefore, been obtained for a number of contrasting British soil series by measuring isotopically exchangeable phosphate and phosphate in solution for samples from differentially enriched field experiment plots where the phosphate residues can be assumed to have attained equilibrium. The results show major differences between the different series in the shape and position of the curves, and should enable suitable laboratory procedures to be established. Similar studies have also been done on a selection of Canadian soils, by Professor J. A. Robertson, Department of Soil Science, University of Alberta, while on sabbatical leave in the department. The results remain to be fully evaluated, but the indications are that depletive cropping of enriched soil in pot cultures gives isotherms coincident with those obtained from differentially enriched field samples; laboratory adsorption isotherms using a reaction period of 24h, however, do not correspond closely with results for samples which have attained equilibrium in the field. 605

Another important question is the practical implications of quantity-intensity relationships and soil properties in relation to possibilities of improving evaluation of soil phosphate status for advisory purposes. To extend studies in this area changes in phosphate intensity and quantity measurements have been monitored at monthly intervals in samples from incrementally enriched field plots, and with the assistance of the East of Scotland College of Agriculture and the West of Scotland Agricultural College soil samples from contrasting soil series in these regions have been collected for evaluation of phosphate status by laboratory and pot culture techniques. 601, 608

In collaboration with the Department of Soil Organic Chemistry, attention continues to be given to the distribution of inositol phosphates in different soil series, and to their interrelationships with inorganic phosphate and other soil constituents, especially sulphur and soluble iron and aluminium. Two papers mentioned in earlier Reports, a review of soil organic phosphates[44] and an account of the characterization of phosphate

esters isolated from sodium hydroxide extracts[45] have now been published. 317, 602

Sulphur

Work has continued on the nature and distribution of organic sulphur compounds and fractions in soils. Two accounts of these studies[96, 97] have been submitted for publication, and a chapter on sulphur in soil organic substances[46], mentioned in several previous Reports, has appeared. 602

Over 90 per cent of the total sulphur in groups of ten freely-drained acid surface soils representing four contrasting soil series in north-east Scotland is in an organic form, compared with an average of 40 per cent for a group of ten calcareous soils[96]. The main subdivision of soil organic sulphur is into organic sulphate and carbon-bonded forms, and again there is a marked contrast between the acid and calcareous soils. In the latter, carbon-bonded sulphur is the dominant fraction, accounting for an average of about 80 per cent of the total organic sulphur, leaving only about 20 per cent as organic sulphate. In the acid soils, on the other hand, organic sulphate accounts for more than half of the total and is the major component. Direct measurement of carbon-bonded sulphur by treatment with Raney-nickel and sodium hydroxide underestimates the amount in most of the present soils and the total is best measured by difference between the total organic sulphur and organic sulphate. The latter, in turn, can be reliably determined by subtracting the phosphate-extractable inorganic sulphate from the total sulphate determined by reduction to inorganic sulphide with a reagent containing hydriodic, formic and hypophosphorous acids. The reactive carbon-bonded sulphur directly determined by the Raney-nickel treatment, however, is highly correlated with the total carbon, nitrogen and organic sulphur, suggesting that it comprises a well-defined group of compounds. Unlike the total organic phosphorus, the total organic sulphur is also highly correlated with carbon and nitrogen, indicating that it is predominantly an integral part of the soil organic matter. The significant correlations which occur between organic sulphur and categories of soluble aluminium and iron, especially the former, may accordingly be regarded as indirect reflections of corresponding strong correlations between these constituents and the soil organic matter. 602

A high proportion of the organic sulphur can be extracted from the acid soils by ultrasonic dispersion in aqueous acetylacetone at pH 8. Gel permeation chromatography of the extracts from five soils has yielded materials containing from 14 to 60 per cent of the total organic sulphur[97]. In most cases, four distinct fractions have been obtained, containing from 21 to 38 per cent C, 0·2 to 2·1 per cent N, 0·1 to 0·8 per cent S, and considerable amounts of iron and aluminium, presumably incorporated in organic complexes. These materials have been isolated under very mild conditions and should provide useful starting materials for further qualitative investigation on the nature of soil organic sulphur. 602

The inorganic sulphate contents and sorption relationships in the acid soils have also been investigated, and an account of the results[98] has been submitted for publication. In keeping with the fact that sulphur deficiency

is not a problem in the area, all four groups are well supplied with available sulphate. The phosphate—extractable inorganic sulphate ranges from 13 to 60 mg S/kg soil, of which from 17 to 84 per cent, with an average of 58 per cent, is in the adsorbed form. The average adsorbed sulphate contents of the four groups, however, are closely related to their differing abilities to adsorb sulphate from laboratory suspensions and, as in the case of phosphate, both properties show marked influences of parent material. Unlike phosphate retention, however, sulphate sorption in most instances seems to depend more on active iron than aluminium, and is accordingly much less affected by the pedological drainage status. The emphasis is, therefore, on the Soil Association rather than the soil series, but both are significant and provide a rational basis for interpreting the sulphur relationships of these soils. 601

Potassium and Magnesium

Detailed laboratory and pot culture studies have been started to examine influences of parent material, pedological drainage status and soil properties on the short-term and long-term potassium and magnesium supplying powers of Scottish soils. Particular attention is being given to the significance of differences in clay mineralogy, and in consultation with the Departments of Pedology and Soil Survey five contrasting soil series have been selected from this point of view for the initial study. These are the Insch, Foudland, Strichen, Countesswells and Caprington series, of which the first four are freely-drained and the last is in the imperfectly drained category. Samples of the surface soil and a subsoil horizon were collected from two sites on each series, one rich and the other low in nutrients. For each soil, the quantity-intensity relationships for both nutrients are being characterized by means of adsorption and desorption isotherms in 0·01 M calcium chloride suspensions. To follow changes in both exchangeable and non-exchangeable forms, the potassium and magnesium contents of the surface soils are being progressively depleted by continuous cropping with ryegrass in pot cultures. 611

An account of earlier work (Annual Report, No. 41, 1972/73) on the effects of pH on potassium adsorption and desorption[47] has now been published. 611

Soil Acidity and Cation Exchange

Work described in the last three reports on relationships between soluble aluminium, calcium-aluminium exchange reactions, and soil pH[48] has now been published. Important features of the results are the differences in the curves relating pH to soluble aluminium for soils of different origin and composition. To assess the implications of these differences in relation to plant growth, preliminary experiments have been carried out with barley seedlings in pot cultures, and soils have been examined from farmers' fields where barley was failing because of acid soil conditions. The indications were that the critical pH, measured in 1 : 1 equilibrium suspensions in 0·004 M calcium chloride, at which root development was severely restricted, varied between 4·2 and 4·5. These values are about 0·4 less than would be

obtained in water suspensions. The corresponding critical aluminium concentration in solution ranged from 0·04 to 0·10 millimolar. The only clear difference between soils was a lower critical pH in a light sandy soil and a peat, reflecting lower concentrations of aluminium in solution compared with loamy textured soils. A full examination of the factors involved, however, would require assessment also of calcium and phosphate relationships and consideration of varietal differences. 605

A report on some aspects of the chemistry of aluminium in acid soils[99], described in last year's Report, has been accepted for publication. The difficulties that arose in defining the aluminium status of soils with regard to the readily-soluble or mobile fractions have been rationalized, enabling reasonable methods to be proposed for determining the ill-defined exchangeable fraction and for characterizing the solution with regard to the aluminium: divalent cation activity ratio. More rigorous studies of aluminium in soil solutions will need to take account of hydroxy-aluminium polymers, for it has been shown that they constitute a considerable proportion of the total aluminium in dilute salt extracts[100]. 605

A critical examination of procedures for measuring the cation exchange capacity of soils[101], including a discussion of the issues involved in selecting methods for particular purposes, has been accepted for publication. 605

Soil Physical Measurements

Using the methods described in last year's Report, progress has been made in carrying out systematic measurements of the moisture release characteristics, pore-space relationships, and hydraulic conductivity of soil series from different parts of Scotland. Profiles from twelve series have been examined during the year, and facilities have been established for faster throughput of samples. 612

Radioactivity

Radioactive ^{32}P has been extensively used in the inorganic phosphorus work summarized above, in pot culture as well as laboratory studies, and services and collaboration continue to be supplied to other departments. 601, 605, 613, 5613

Ion flux studies in the Department of Plant Physiology have involved the use of radioactive isotopes of several major cations and anions as tracers in plants. With ^{42}K the disadvantage of its short life is readily overcome by using high initial specific activities because this radionuclide is readily available and inexpensive. As shown by the few reports in the literature, the main difficulties in finding a suitable tracer occur with magnesium. The istotope ^{28}Mg, half life 21·3 h, however, produced by Brookhaven National Laboratory, U.S.A. by the ^{26}Mg (t,p) ^{28}Mg reaction in a Van de Graaff generator, has been successfully used in ion flux studies; it has also enabled the distribution of magnesium in plant roots to be clearly followed by autoradiography. 407, 613, 5613

To facilitate studies on the distribution of calcium in seedlings, a stock of about 2000 wheat seed labelled with ^{45}Ca was produced for the Department of Soil Organic Chemistry by growing plants to maturity in labelled culture solution. Though radiation damage might be expected at a specific

activity of about 8 μCi/mg Ca in the seed, the much higher level of 23·3 μ Ci, compared with only 0·7 μ Ci in a previous experiment, was attained without any evidence of radiation effects. Collaboration with the Department of Soil Organic Chemistry has also continued on the decomposition in soil of labelled plant material. 305, 309, 5613

Advisory Work

During the year over 5600 soil samples were received from the Advisory Officers of the North of Scotland College of Agriculture. Except for about 150 horticultural samples these all came from agricultural land. The lime status and the phosphate and potassium contents were assessed in all cases and magnesium was examined in 780 samples. In collaboration with the Department of Spectrochemistry, trace elements, mainly cobalt and copper, were assessed in nearly 600 soil samples and 55 crop samples, involving problems of animal health as well as crop growth. 610, 5205, 5206

Many of the requests for copper assessments arose from suspected deficiencies in cattle. Experimental work and advisory examination of soil and herbage samples have shown that only a very small proportion of these stock problems are associated with soils sufficiently deficent in copper to limit the yield of cereal grain. Occasionally, mainly in areas classified as poorly-drained by the Soil Survey, the herbage and soil contain greater than normal amounts of molybdenum, and it is well known that an excess of this element in grassland herbage can induce symptoms of copper deficiency in the animals. In such cases, liming, which is essential for satisfactory crop yields, especially of barley, tends to increase the uptake of molybdenum, and extra care is, therefore, desirable in deciding the amount to apply. This is true also for copper deficient soils, since liming may tend to reduce the copper content of the herbage. Application of about 5·7 kg/ha of copper, however, should remove any such risk, because normal dressings of lime have practically no effect on the content of copper in herbage on soils with adequate copper contents. On many soils in northern Scotland belonging to soil series classified by the Soil Survey as freely-drained, the copper content of pasture, especially during the summer, may not be adequate for cattle even though the soil is well supplied with copper and supports normal growth of cereals. The copper content in the dry matter of mixed herbage from temporary leys on many of these soils is usually between 4 and 8 ppm, compared with the level of 10 ppm which has been suggested to be desirable. Normal dressings of copper, however, do not usually raise the content in grasses to this level. Similarly, the dry matter of turnip roots and cereal grain and straw also normally contains less than 10 ppm of copper and soil dressings produce only a small increase. 609, 610, 5205

In collaboration with the Department of Pedology, requirements for phosphate, potassium, calcium and magnesium were assessed in 72 soil samples from forest nurseries. 117, 608, 5206

7. STATISTICS

The main work of the department is of a consultative and advisory nature. In the specialized service provided to other departments the areas covered include experimental design, statistical analysis, model-building, data preparation and processing, and computer operation and programming. The statistical aspects of the work have required the greater proportion of time and effort, and all project packages, representing all departments, have been serviced.

During the year the department moved to a much more convenient part of the main building vacated by the Soil Survey of Scotland. With the addition of an IBM System/7, the large computer room now contains two computers linked together and the various items of peripheral equipment.

Members of staff have attended courses of instruction on the use and programming of the System/7 at the IBM Customer Education Centre. The department has also been represented at meetings of the Institute of Statisticians, the Biometric Society and the ARC Crop Science Model-Builders' Group, at a Royal Statistical Society Conference on the analysis of experimental data, and at an ARC statisticians' symposium on aspects of statistical computing, collaboration and consultation. Mr R. H. E. Inkson, who is a member of the International Society of Soil Science Working Group on Soil Information Systems, attended the group's first meeting at Wageningen in The Netherlands.

Computing Service

The IBM System/7 uses the 1130 as a host computer although both can operate independently. The reduction of the cycle time of the 1130 from 3·6 to 2·2 microseconds and the access to the larger disk storage capacity of the System/7 have both contributed to a significant increase in computing power. We are grateful to the JII/FRI Computer Group for their modified operating system which has now been loaded and has been undergoing testing and familiarization along with the IBM operating and programming systems. Further improvements and economies in operation have been effected. But, in spite of this and the increased power of the system, the demands for computer time have meant continuous operation throughout the working day and frequent out-of-hours operation. Considerable assistance has been given in the reorganization and implementation of a number of user programs. 105, 203, 703

Pedology. The joint account of the application of principal components analysis to the method of discrimination used on the composite mass spectra obtained from the decomposition products of pyrolysis[15] has now been published. The processing of data from electron-probe microanalysis, from X-ray silicate analysis and from the auto-analysis of rainfall, foliage, litter and other samples continues on a regular routine basis.

107, 108, 109, 111, 112, 114, 115, 116, 117, 703, 5703

A statistical package for multivariate analysis and time series analysis has been developed for the processing and interpretation of survey data.

New methods of map analysis have been adapted from the IBM numerical surface techniques and contour mapping program package. Digitization of all previous peat survey data is being undertaken and contour maps have been produced showing the surface and bottom (prior to peat formation) contours of peat deposits. This work is being done to compare and analyse the distribution and formation of peat types in Scotland with a view to correlating the information with that to be produced by photogrammetric means and deriving a system of peat classification. 112, 117, 703, 5703

Spectrochemistry. Standard correlation and regression programs have been used to enable background corrections to be made to trace element signals from a multi-element emission spectrometer used for the analysis of soils and rocks. The program which was developed for the simulation of electron paramagnetic resonance powder spectra is now in use as a regular service. 201, 203, 5703

Soil Fertility. A new program has been written to calculate and tabulate bulk density, total porosity, and the volume fractions of air and of water at various suction pressures for sample soil cores. 612, 5703

Soil Survey. A regular service is provided for card punching and computer operation for the plant sociological methods in use for vegetation surveys. 802, 5703

Advisory and Collaborative Work

Pedology. A further NPK experiment of central composite design with additional control treatments has been planned, and random sampling schemes prepared for the collection of litter fall and of rainwater as throughfall and stemflow, for the study of the relationship between tree growth and nutrient uptake in pole-stage Sitka spruce. In addition to the annual girth and height increments and foliage analysis data which require statistical analysis, the routine processing of whole tree sampling data continues as described in last year's Report using the program FORET which provides unbiased estimates in log/log regressions. An investigation of nitrogen utilization and uptake requirements for maximum volume growth also used the program FORET, a standard regression program and a specially written program for the estimation of nitrogen immobilization. 115, 701, 703, 5701, 5703

A study of nitrogen mineralization, involving a comparison of aerobic and anaerobic incubation, made use of analysis of variance and covariance for factorial experiments. Whole tree sampling was also used in a water level experiment with lodgepole pine, and plot estimates obtained by the program FORET. 110, 116, 5701, 5703

The forestry experiments at Culbin and Alltcailleach continue to provide a wide range of data for processing and statistical analysis. Among new computer programs used in this connection are some for storing and editing computer data files. A joint account of some of the work on litter fall and crown leaching[73] has been accepted for publication. A comparison of annual ring-width with a number of climatic factors has required the use of some special computer programs in addition to those for standard correlation and regression analysis. 117, 701, 703, 5701, 5703

Three climatic factors, mean annual temperature, altitude and precipitation have been used in correlation and regression studies with pyrogram ratios based on peak-height and peak-area. These techniques were also used in a study of the prediction of hydroxyl activity from determination of silica, aluminium and iron[63]. 105, 107, 5701, 5703

Spectrochemistry. Inverse estimation was used from regression equations relating the apparent percentage to the actual percentage of ^{15}N in a study involving different types of discharge tube. 202, 5701, 5703

Soil Organic Chemistry. Collaboration has involved the use of analysis of variance in an examination of methods of analysis and in experiments on the specific activities of sugars measured at different temperatures. For 7 different sugars and 5 buffer solutions, linear regression equations have been derived for calibration. These have been used for inverse estimation and the determination of inverse tolerance limits in a joint account of the work[85] which has been submitted for publication. 303, 305, 5701, 5703

Plant Physiology. Nutrient contents and their ratios, and observations on various plant and tree parts have provided data for analysis of variance and covariance from designed experiments and for correlation and regression analysis from other investigations. Curvilinear regression has also been used to examine the pattern of variation of a range of elements and the catalase and peroxidase activity along the length from heel to rose ends of potato cores. 401, 402, 701, 5701, 5703

Microbiology. The use of square root and logarithmic transformations was investigated in a study of the population changes with time of *A. Chroococcum* in pure culture and in soil maintained at different suctions both with and without colpoda. The logarithmic transformation of the data was indicated since the standard deviations were proportional to the weekly mean counts. A computer program was written to process the data and to carry out the subsequent statistical analysis. The work on the relationship between the numbers of bacteria at various depths in peat and the chemical properties of the peat[94] has been completed and submitted for publication. The paper in last year's Report, describing a rapid laboratory procedure using a microdiluter and the statistical method for estimating bacterial and protozoan populations in soil and peat[37], has now been published. Comparisons of mixed culture and clonal culture populations of Heteromita have been made in terms of various physical measurements of size. 503, 504, 505, 701, 5701, 5703

Estimates and summaries of protozoan populations in numbers per gram of oven-dried soil with 95% fiducial limits are carried out on a regular routine basis. 504, 5701

Soil Fertility. The range of experimental designs currently in use for field experiments includes randomized blocks, Latin squares, lattice squares, central composite designs and factorial arrangements, some of which have split-plots, confounding or partial confounding, and fractional replication. 601, 607, 608, 609, 701, 5701

The relationship between crop yields and soil pH has been examined for

grass, barley and swede crops in three different soil groups. The regression equations were linear in some cases and quadratic in others. Differences between the groups of soils were examined and results combined where possible. An exponential regression equation of the type $y=a+br^x$ has been used to predict the lime content of soil from the pH value. An interactive computer program was written to allow the choice of values of r to minimize the sum of squares of residuals. The method has been tried with 17 sets of data representing several years and sets of data have been combined where possible. 608, 701, 702, 5701, 5703

Studies of the pattern of growth and development of barley and swedes have continued with data from periodic samples taken during the growing season providing both chemical and physical measurements. Variates derived from these include ratios, growth rates and net assimilation rates. 607, 5701, 5703

The relationship between excess base in plants and crop yield measurements has been examined for different varieties of crops. Other uses of correlation and regression analysis have been concerned with a range of crop and soil properties. In the case of relating aluminium concentration and the logarithm of the activity ratio to rapidly estimated values, a comparison was made between Hotelling's test of the difference between correlation coefficients and Williams' adaptation of it. A study of the pattern of variation and the variability in nitrogen and phosphorus measurements taken at various depths at a number of sites in different years was made and the results combined. 601, 602, 603, 604, 606, 608, 701, 5701, 5703

8. SOIL SURVEY

The year has brought increased demands for soil survey information and the work of the Survey is becoming correspondingly widely known. Requests for soil and land use capability surveys have come from planning officers of the Regional Councils. The British Gas Corporation has continued to find the soil maps of help in assessing trafficability along the wayleave of their pipelines. An increased awareness of the need for more information about land drainage has involved the Survey in lectures and field excursions to demonstrate soil types to College advisory staff and to inspectors of the Department of Agriculture. A keen interest is being evinced in the land use capability classification by Lands Branch officers of the Department, by College advisers and private estate owners and factors. Most of the requests for information and help have been met, but the demand for land use capability maps exceeds the Survey's current ability to produce these maps, especially in the areas, particularly in the north-east, which have in the past been surveyed for soils but not for land use capability.

Systematic soil survey on a scale of 1:25 000 has continued in the areas listed below. During the current season 1015 km² (392 square miles) have been surveyed, 110 on Sheets 118, 119, 120, 121, 122 and part 117 (Orkney), 185 on Sheets 109 (Auchentoul) and 115 (Reay), 60 on Sheet 103 (Golspie), 145 on Sheet 74 (Grantown), 90 on Sheet 75 (Tomintoul), 40 on Sheet 65 (Balmoral), 100 on Sheet 47 (Crieff), 35 on Sheets 30 (Glasgow) and 38 (Loch Lomond), 175 on Sheet 23 (Hamilton) and 75 on Sheets 5 (Kirkcudbright) and 9 (Maxwelltown). Extensive revision and data collection have been carried out on Sheet 53 (Ben Nevis) and the mainland parts of Sheets 51 (Coll) and 52 (Tobermory) and a number of larger scale special surveys have been completed.

Land use capability assessments have been made concurrently with all new soil mapping. Assessments have been completed for Sheets 85 (Rothes), 84 (Nairn), 66/67 (Banchory/Stonehaven) and 33/34 (Haddington/Eyemouth), totalling some 4800 km² (1850 square miles). About 600 km² have been classified on Sheet 57 (Forfar) and a further 100 km² on Sheet 76 (Inverurie). A provisional land use capability map has been prepared for the Morvern-Ardnamurchan area of Sheets 51, 52 and 53.

One hundred and forty profiles have been described and sampled for analysis, mostly with the aid of the Smalley excavator.

Members of staff have attended meetings of the British Society of Soil Science, the British Cartographical Society and the Quaternary Research Association and taken part in symposia on Native Pinewoods and Heather Moorland sponsored by the Nature Conservancy Council and the Institute of Biology respectively.

The department is represented on the Ordnance Survey Advisory Committee, the Ministry of Agriculture, Fisheries and Food Working Party on Land Use Capability Classification, the Department of Agriculture and Fisheries for Scotland Working Party on Land Use Capability for the Low

Ground, the Scottish Agricultural Development Council Field Drainage Group and the related College Area Drainage Liaison Panels. 801, 802, 804

Sheets 118, 119, 120, 121, part 117 (Orkney Islands)

Approximately 110 km² (42 square miles) have been surveyed in the parishes of Stromness, Evie and Birsay and on the Island of Hoy. The soils of the granite-schist injection complex around Stromness have been examined and soils generally akin to those of the Strichen Association mapped, peaty gleyed podzols and, on steeper slopes, peaty podzols being most common; the soils are not extensive. A small area of complex based on outcrops of the granite-schist rock has been mapped around the farm of Croval. In the immediate vicinity of the granite-schist mass a degree of granite-schist contamination of otherwise Thurso Association drift was noted. Poorly drained soils developed on strongly weathered rock, more or less *in situ*, have been mapped around Stromness; such soils were first encountered in Graemsay and have been named, provisionally, the Ness series.

Freely drained soils on an interesting succession of small fluvioglacial sand mounds have been found along the Innertown to Outertown Road, Stromness. Pending possible correlation, these soils have not so far been named.

In the parishes of Evie and Birsay soils of the Thurso Association have been mapped with the podzols of the Bilbster series dominating; rock was generally close to the surface especially around the Costa district of Evie and a complicated picture of shallow and normal phases of soils of the Thurso Association emerged. On hill-ground, areas of deep and shallow peat have been mapped, the peat being generally cut-over. Areas of intensively cut-over peat have been mapped as a complex of thin peat and peaty gley (Olrig series) with subordinate peaty gleyed podzol (Camster series); discrete areas of Olrig series and Camster series were also encountered.

The soil survey of Hoy has been continued with the mapping of the hill-ground and the arable ground of the parish of Walls. Peat and peaty gleyed podzols, Dunnet series of the Dunnet Association, have been mapped over the hill-ground whilst in South Walls soils of the Thurso Association were found, mainly non-calcareous gleys (Thurso series), podzols (Bilbster series) and peaty gleys (Olrig series). Rock was usually close to the surface. Small pockets of Canisbay Association drift were also met.

Fourteen profiles were described and sampled. 801

Sheets 109 (Auchentoul) and 115 (Reay)

About 185 km² (70 square miles) have been surveyed and 11 profiles described and sampled. The district mapped lies between the Strath of Kildonan and Ben Armine Forest and is formed of Moinian rocks with some Middle Old Red Sandstone sandstones and conglomerates in the extreme south-east. The soils mostly belong to the Strichen Association and the mapping units are generally soil complexes, the most common one occurring on sloping and gently undulating ground, consisting of peaty

podzols, peaty gleys and shallow peat. A complex of similar soils but on rocky landscapes and including ranker soils is less extensive, and a third complex, restricted to areas of hummocky moraine, comprises peaty podzols and deep or shallow peat (Strathnaver complex). Peaty podzols (Gaerlie series) and peaty gleys (Hythie series) are sometimes sufficiently extensive, particularly in the eastern part of the area, to map as separate series. A cultivated phase of the Gaerlie series has been mapped on small patches of formerly cultivated land around old crofts. In the Strath of Kildonan some humus-iron podzols (Strichen series) have been delineated on steep slopes and on moraine mounds. Oroarctic soils have been mapped above 600 m (2000 feet) on the hills of the Ben Armine range. Soils of the Berriedale Association occur on the area of M.O.R.S. rocks and are predominantly peaty podzols (Berriedale series) with oroarctic soils present on the top of Ben Uarie which lies immediately to the south on Sheet 103. Soils of the Corby Association occur as a few small scattered patches of a complex of peaty podzols (Tarbothill series) and peat, and are largely confined to the western part of the district. Shallow and deep peat are common throughout, the latter being particularly extensive around the headwaters of the River Skinsdale. 801

Sheet 103 (Golspie)

An area of about 60 km² (22 square miles) lying to the west of Loch Fleet has been surveyed. The underlying rocks are predominantly of Moinian age with some M.O.R.S. conglomerates in the eastern part. Most of the soils belong to the Strichen Association and comprise peaty podzols (Gaerlie series) and peaty gleys (Hythie series), a complex of peaty podzols, peaty gleys and shallow peat being a common mapping unit. The conglomerates form three small steep hills on which peaty podzols occur on the lower slopes and peaty ranker soils, together with bare rock, on the upper slopes and summits. Provisionally these soils have been included in the Berriedale Association. Shallow and deep peat are common throughout the area.

Eleven profiles developed on raised beach and alluvial materials have been described and sampled. 801

Sheet 85 (Rothes)

Land use capability maps on a scale of 1:25 000 covering the area of Sheet 85 (1120 km²) have now been completed. About 36 per cent of the land is included within Classes 2, 3 and 4. This arable, or potentially arable land, is almost evenly divided between Classes 3 and 4 with minor areas of Class 2 land along the inland edge of the Moray coastal zone and along the Spey Valley. The remaining 64 per cent within Classes 5, 6 and 7 reflects the extensive moorland and blanket peat between 275 m and 840 m.

Correlation of the boundary between Sheets 85 and 75 relating to both soil and land use capability maps at 1:25 000 has also been carried out. 801

Sheets 84 (Nairn) and 74 (Grantown)

The field season has been devoted to three main objectives—systematic soil survey of the Monadhliath Mountains, land use capability survey of

Sheet 84 (Nairn) and site investigations for the new A9 trunk road (reported under Special Surveys).

Systematic survey of approximately 145 km² (55 square miles) within the Monadhliath Mountains was completed before access was restricted for grouse shooting and deer stalking. The area centred on the headwaters of the River Dulnain with the northern and southern limits marked respectively by the Rivers Findhorn and Spey.

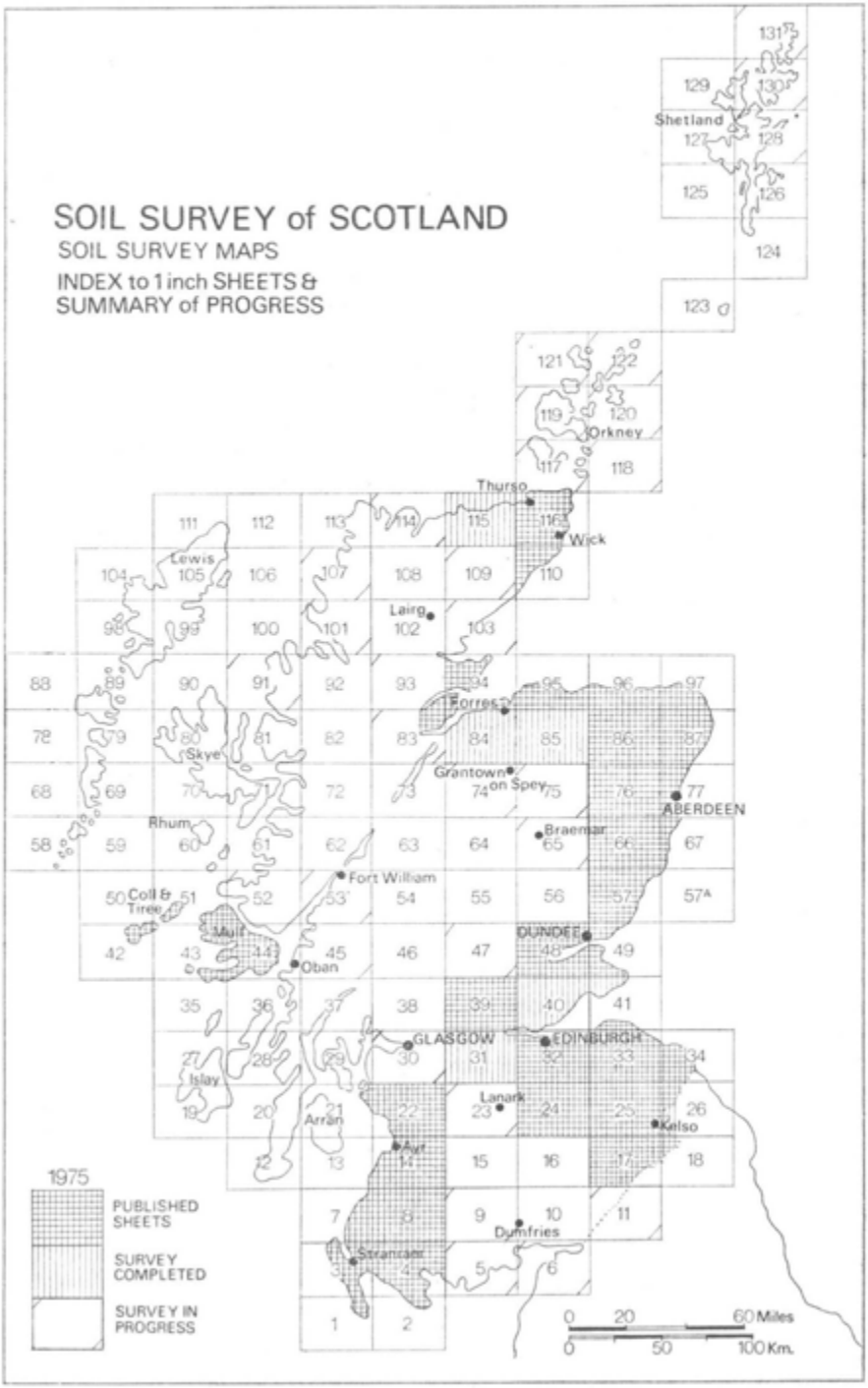
Although rising to altitudes of nearly 900 m (3000 feet) in the south-east, the mountains represent a broad plateau with the dominant level between 600 m (2000 feet) and 750 m (2500 feet). This relief has been developed on rocks of the Moinian Assemblage and modified by glacial and riverine action.

Extensive hill peat about 1·5 m thick occupies most slopes on the plateau although up to 4m of peat have been recorded in col and basin sites. A distinctive erosional pattern of dendritic and linear hagging is widespread, often exposing the iron-pan of an underlying peaty gleyed podzol. Deeply weathered schist is also frequently exposed beneath the peat. Two forms of redistributed peat have been encountered. In the east, long flushed ribbons of peat which are characterized by a *Nardus stricta* and *Juncus squarrosus* vegetation occupy concave slopes below col sites. In the slightly wetter and more exposed west, the redistributed peat normally occupies small depressions and is devoid of vegetation. Whereas the hill peat extends to the edge of the steep-sided Findhorn valley in the north, it is of limited extent and less eroded in the Monadhliath foothills which fringe the Spey valley where it is mainly confined to valley floors and the lower concave slopes.

Above 600 m (2000 feet) shattered schist rock, or shallow drift, forms the parent material of most soils. Occasionally there is an overlying veneer of well sorted fluvioglacial sands and gravels, especially in association with deeply incised valleys or meltwater channels.

On the summits and convex slopes above 750 m (2500 feet), alpine podzols of the Strichen Association, have been mapped. This zone is characterized by *Cladonia* sp., *Empetrum nigrum* and stunted *Calluna vulgaris*, with an abrupt boundary between the mineral soil and the surrounding hill peat. Of specific interest are the isolated occurrences of 'peat tables,' usually less than 1 metre thick and 10 metres in diameter overlying the alpine podzols. These may represent the remnants of a more widespread peat cover. Peaty gleyed podzols with a well developed iron pan, Gaerlie series, replace the alpine podzols on steep slopes. Such slopes have a distinctive vegetation dominated by *Vaccinium myrtillus*, *Juncus squarrosus*, *Nardus stricta* and *Juniperus communis*.

South of the River Dulnain to the foothills along the Spey valley, the valleys and lower slopes are covered by the schist till of the Strichen Association which is frequently overlain by gravelly loamy fine sands of the Dulsie Association. The dominant soils include peaty podzols, both freely and imperfectly drained, and peaty fragogleys. On the higher slopes and strongly glaciated summits below 600 m (2000 feet) sub-alpine podzols and peaty podzolic rankers belonging to the Strichen Association are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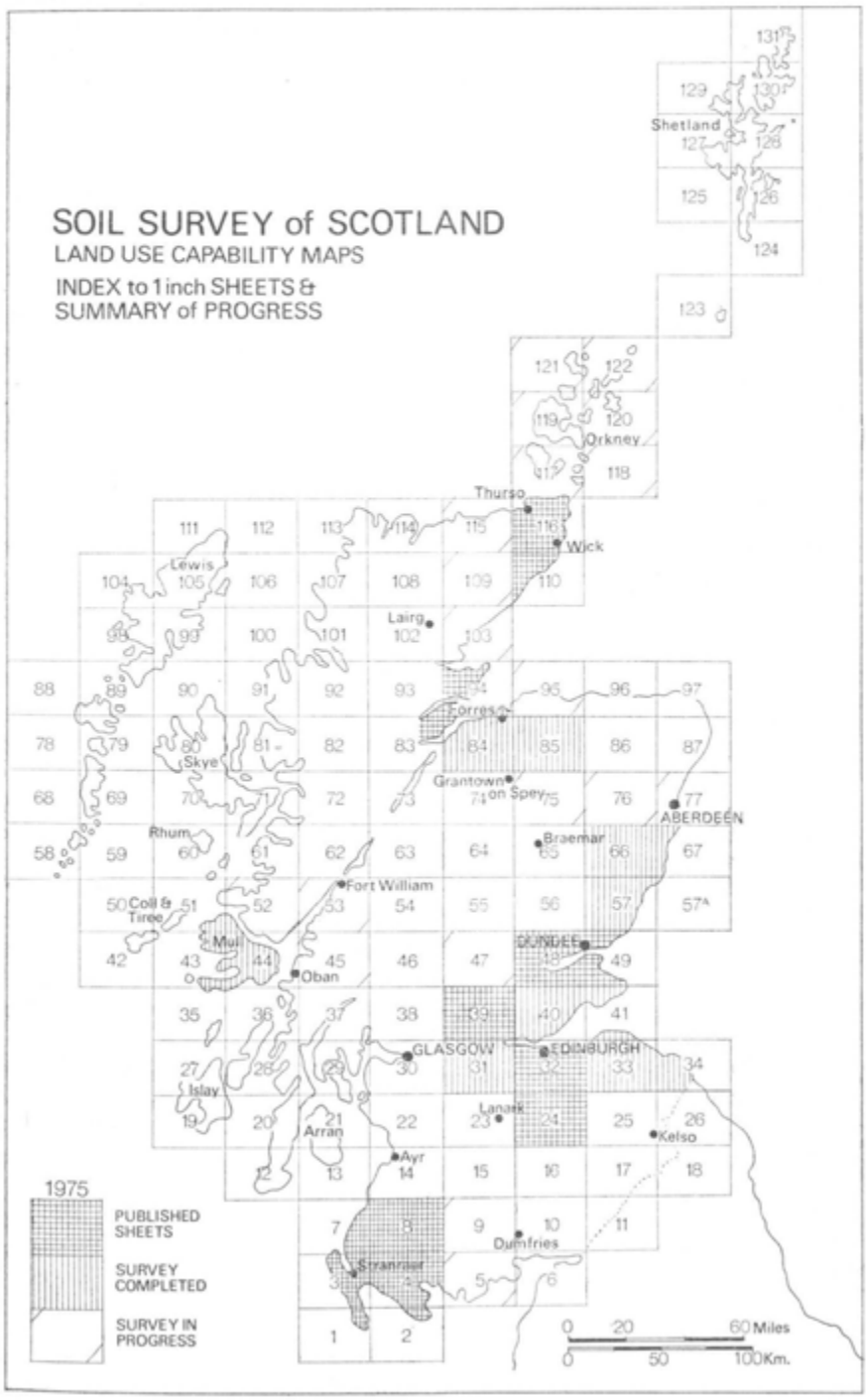
Braemar
Fort William
Coll & Tiree
Mull
Oban
DUNDEE
GLASGOW
EDINBURGH
Islay
Arran
Lanark
Kelso
Ayr
Dumfries
Stranraer
1975
PUBLISHED SHEETS
SURVEY COMPLETED
SURVEY IN PROGRESS
0 20 60 Miles
0 50 100 Km.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Kelso
Ayr
Dumfries
Stranraer
1975
PUBLISHED SHEETS
SURVEY COMPLETED
SURVEY IN PROGRESS
0 20 60 Miles
0 50 100 Km.

developed on shattered rock or shallow drift. The sub-alpine podzols are limited in extent and, where bedrock is close to the surface, drainage may be imperfect.

A complex, consisting of alpine or sub-alpine podzols, rankers and rock with varying amounts of peat, is widespread. Pending correlation, no name has been assigned. Two other complexes have been identified. The first consists of abundant rock with associated scree and colluvial soils and has been used to map the strongly glaciated steep slopes of the Spey and Findhorn valleys. The second comprises podzols of the Dulsie Association with a variable amount of rock.

The land use capability assessment of Sheet 84 (Nairn) has been completed. Following the preparation of 1:25 000 land use capability base maps, a collaborative field programme was undertaken with the advisory officers of the North of Scotland College of Agriculture and the inspectors of the Department of Agriculture. Each 1:25 000 map was subjected to examination and correlation in the field. Upon completion of this review, the 1:63 360 land use capability map was finalized. 801

Sheet 76 (Inverurie)

The land use capability survey has been continued westwards and correlation has been carried out with Sheet 75 (Tomintoul) along the western margin. 801

Sheet 75 (Tomintoul)

About 90 km² (35 square miles) have been surveyed and 3 profiles described and sampled. The Smalley excavator was used to dig 10 pits to establish the nature of soil parent materials.

In the area around Tomintoul about 50 km² (20 square miles) have been mapped, including the major part of the Forestry Commission's Glenlivet Forest. Most soil parent materials are derived from acid schists, slates, quartzites and Old Red Sandstone sediments; these rocks and their derived drifts form soils of the Strichen, Foudland, Durnhill and the provisionally named Tomintoul Associations respectively. The soils tend to be freely drained but the Tomintoul Association has a relatively high proportion of poorly drained gleys and peaty gleys because of finer textures at depth.

Around Strathdon about 40 km² (15 square miles) have been mapped, including Tornashean Forest owned by the Forestry Commission. The soils of Tornashean are developed mainly on basic igneous rocks and their derived drifts and belong to the Insch Association. A northern outlier of the forest in Glen Nochty has soils derived from dark carbonaceous slates and ultra-basic rocks, mapped in the Foudland and Leslie Associations respectively. The coarse texture and good base-status of the soils and the low rainfall and hilly relief are responsible for the low proportion of soils with thick peaty surface horizons and for the predominance of freely drained soils. Below an elevation of 500 m (1600 feet), not far below the upper afforestation limit, most soils are also improvable for agriculture and the land is thus rated as Class 5.

Revision has established the validity of distinguishing the Corriebreck Association, the soils of which are formed from a mixed drift containing a

significant amount of ultra-basic material. Separation of the Dulsie Association in the Grantown-on-Spey area has been made where the excavator revealed rounded stones in the sometimes rudely-stratified loamy sand drift, a coarser material than the unsorted drift of the previously mapped Strichen Association. 801

Sheet 65 (Balmoral)

About 40 km² (15 square miles) have been surveyed to the south-west of Braemar. The soils are derived from schists, quartzites, felsites and calc-silicate rocks, and have been mapped within the Strichen, Durnhill, Knockskae and Deecastle Associations respectively. Some of the schists, those separated as mica-schists on the geological map, form soils which are more base-rich than most Strichen Association soils on the evidence of a higher proportion of brown forest soils and the presence in 'flushes' of base-rich plant indicators, for example the yellow mountain-saxifrage *Saxifraga aizoides* and the Scottish asphodel *Tofieldia pusilla.* 801

Sheet 66/67 (Banchory/Stonehaven)

The land use capability assessment of this area has been completed. Following consultation with advisory officers from the North of Scotland College of Agriculture and with officers of the Lands Branch from the Department of Agriculture, a coloured draft map on the 1:63 360 scale has been submitted to the Ordnance Survey. 801

Sheet 57 (Forfar)

The land use capability survey has been continued and a further 589 km² (227 square miles) have been completed covering the whole area south of the River South Esk together with the north-east corner of the sheet from Benholm to Morphie. 801

Sheets 51 (Coll), 52 (Tobermory) and 53 (Ben Nevis)

The 1975 field season has been devoted entirely to revision and data collection from previously mapped areas. Six hundred and eighty morphological and site descriptions have been made of profiles in 34 sample areas belonging to 5 soil associations. The sample areas and the points within them were selected in random manner and attention has been focussed on those soil complexes known to have the highest potential for agricultural use. An impression of the variability of the complexes recognized is given by the fact that approximately 60 per cent of the major soil subgroups and miscellaneous soils (peat, rock and alluvium) occurring within any association can be recognized in any one complex of that association. It is almost always possible to recognize two dominant soils within a complex however, which together occupy about 60 per cent of the complex. The better-drained complexes (i.e. those with higher proportions of brown forest and podzol soils) tend to have a greater range of included minor soil types than the wetter complexes.

As in other parts of west and north-west Scotland the principal feature of the soils described is the influence of organic matter throughout the soil profile. Wherever water flow is impeded within the soil profile, for example

by the presence of rock, induration or iron-pan, organic matter is deposited. Horizons enriched in humus can be present in all genetic soil groups and in any position within the profile. Munsell values and chromas are frequently low, textures are loamy or sandy, and the solum is dominantly less than 1 m thick.

A strong relation has been found to exist between degree of slope and peat depth; 85 per cent of peat greater than 1 m deep occurs on slopes of less than 8° while 85 per cent of peat between 50 cm and 1 m in depth is found on slopes of less than 16°. On slopes above 16° mineral and organo-mineral soils are prevalent.

Peaty gley soils and peat greater than 50 cm deep occupy the greatest area. Brown forest soils have been found only on parent materials derived from basalt and gabbro and are replaced by podzols on rocks of more acidic character.

A provisional land use capability map has been prepared for the Highlands and Islands Development Board as part of a regional agricultural study.

Six soil profiles have been collected for analysis. 801

Sheet 47 (Crieff)

Approximately 100 km² (40 square miles) of new mapping has been completed during the current field season. This included 25 km² (10 square miles) of the important arable area between Abercairney and Crieff contiguous with the previous year's work and which proved to be an equally complex area to map. The soils encountered have all been described previously and have been included in Alluvium or in the Balrownie, Carpow, Carbrook, Forfar and Laurencekirk Associations.

The remainder of the mapped area adjoins the Abercairney district, but is more conveniently described as being centred on the middle Almond valley between Buchanty in the west and Trinity College, Harrietfield in the east. The underlying rocks of this part of the Almond valley are sediments of Lower Old Red Sandstone age. To the north, the watershed consists of slates and schists of the Dalradian Series of Highland Schists separated from the Old Red Sandstone rocks by the Highland Boundary Fault and its associated fault zone.

The soils of the Almond valley bottom are generally coarse-textured and free-draining and developed on parent materials which have been subjected to variable degrees of sorting by glacial melt-waters. The soils on these water-sorted parent materials have been included in the Corby and Forfar Associations. On the north side of the valley, two distinct topographic units occur. Soils on the steep and bouldery high ground of the schist and slate country north of the Highland Boundary Fault have been included in the Strichen and Foudland Associations. On scattered outcrops of volcanic vent rocks and their associated lavas, small isolated patches of Sourhope Association soils are developed. Across the fault zone between the fault and the river the drift cover is of very mixed origin and content, moulded into subdued relief. Frequent occurrences of gley and peaty gley soils have been included in the Gourdie Association. They are found to be prone to trace

element deficiencies if not managed carefully. The valley side to the south is less rugged and lower in altitude and underlain by Old Red Sandstone sandstone and siltstone mantled by moderately deep drift. The soils developed on this parent material have been included in the Balrownie Association. All of the soils encountered in this district have been previously described.

Ten soil profiles were described and sampled in Strath Braan. 801

Sheet 37 (Inverary)

Survey of Lephinmore Farm (Hill Farming Research Organisation) was continued during October when access to the main survey area was restricted due to stalking. Three hundred and ninety-seven morphological and site descriptions were taken and three profiles sampled. 801

Sheet 31 (Airdrie)

Some 23 soil profiles have been described and sampled in the sheet area north of the Forth/Clyde canal. During this sampling it became apparent that those soils included in the Greenside series did not conform strictly to the conception of this mapping unit south of the canal where it was originally recognized. Accordingly an area of approximately 12 km² (5 square miles) of mapping was revised and those soils formerly included in the Greenside series have been more appropriately assigned to the Forestmill or Macmerry series mapping units and the use of Greenside series north of the Forth/Clyde canal has been discontinued.

Approximately 35 km² (14 square miles) of new mapping was undertaken to complete the 1:25 000 sheets on the western margin of Sheet 31 and part of Sheet 39 so that the 1:25 000 soil maps comprising Sheets NS67, NS68 and NS69 can be prepared for limited circulation. This new mapping included very variable terrain from boulder clay lowland to rocky lava upland and the soils encountered were included in Giffnock, Darleith, Kippen and Stirling Associations. 801

Sheet 23 (Hamilton)

Some 175 km² (68 square miles) have been surveyed around Lanark and south-west of Lesmahagow. National Grid square NS84 has been completed, together with the moorland parts of NS73.

Most of the soils encountered on Sheet NS84 have been surface-water gley soils of the following associations, Rowanhill (Caprington and Rowanhill series), Giffnock (Aberdona series), Sorn (Glenpark series) and Drongan (Drongan series). On Sheet 14 (Ayr) the Drongan series is described as having a parent material of till derived from Upper Coal Measures marls, but around Lanark this series has been found on a variety of deposits. Near Netherburn, over the Coal Measures and Calciferous Sandstone Series, the marl-rich till yields typical examples of this soil with occasional fragments of coal, shale and sandstone present. In the vicinity of the Clyde and associated drainage systems, however, stones and grit fragments are absent from the drift, and it is suspected that the parent material may be shale *in situ* or glacio-lacustrine silty clay drift. All the soils on these parent materials have been mapped in the Drongan Association.

The Lower Old Red Sandstone sediments in the south and east of the area contribute a large proportion of red sandstone to the till. This gives rise to the Glenpark series, but where the sandstone outcrops, or forms a very large proportion of the drift, the Buchanyhill series of the Balrownie Association is developed. Where the red sandstone is absent in the clay loam till to the north and west of Lanark the Caprington, Glaisnock and Rowanhill series of the Rowanhill Association are to be found. The Aberdona series of the Giffnock Association occurs when Carboniferous sandstones are prevalent, as at Cartland and Greentowers, where the till is mainly of sandy clay loam texture. The sandstones of Dillar Hill to the north-east of Lesmahagow, though of Old Red Sandstone age, are hard, grey and, like some of the greywackes of the Lesmahagow inlier and the Southern Uplands, contain many lava fragments. The soils developed on the thin drift on these grey sandstones have been mapped as the Linhope series of the Ettrick Association.

Between Lanark and Lesmahagow some of the igneous intrusions of Old Red Sandstone age produce soil parent materials. The rocks are described as 'felsites,' 'quartz porphyries,' and 'acid porphyites' and are generally hard, very fine grained rhyolites or trachytes. They yield soils of the Bemersyde series of the Bemersyde Association, but where the intrusions are andesitic occasional patches of the Darleith series have been mapped.

On Sheet NS73 large tracts of hill peat have been mapped together with a wide range of soils of the Ettrick Association.

In order to assess the feasibility of establishing a spatial information system, data on 10 environmental and general soil properties have been recorded, together with 17 soil horizon attributes, at all the points of assessment visited during the year's work. Records were made on voice-tape in the field and later transcribed in digital form on to specially designed forms which present the data in a manner suitable for key-punching and computer storage. Initially the new technique slowed down the speed of surveying, but after a period of familiarization the work rate has improved. The results of the experiment have yet to be fully assessed, but it is considered that the extra time spent in the systematic recording of field data is outweighed by the ease of data retrieval. 801

Sheets 5 (Kirkcudbright) and 9 (Maxwelltown)

Approximately 75 km² (30 square miles) have been surveyed, in two main areas, and 59 profiles described and sampled for analysis, mainly from areas mapped in previous seasons.

Mapping has been concentrated in the north of the area in the valleys of the Scaur and Shinnel Waters. The underlying rocks are greywackes and shales of the Ordovician and Silurian systems and the valleys, like those of the Dalwhat and Craigdarroch Waters to the south, are deeply incised and characterized by steep concave slopes. The soils all belong to the Ettrick Association and have been described and reported previously. On the steep concave slopes soils of the poorly drained non-calcareous gley Littleshalloch series extend to the relatively high altitudes, for this area, of 400 metres (1200 feet). Above the steep slopes the inter-valley ridges are

broad and convex in form and are almost bare of drift. The soils are predominantly peaty podzols developed in very shallow frost-shattered rock debris and horizon development is often only weakly expressed, with the iron pan and rudimentary B horizon occurring in the little-disturbed rock. These soils have been mapped in the provisionally named Garryhorn series. The valley bottoms are generally narrow and occupied by loam and sandy loam alluvium overlying alluvial gravels. A considerable proportion of the land in both valleys has been recently afforested.

Survey has also been carried out in the western part of the Ae Forest where, in the difficult mapping conditions of well established forest, considerable help was derived from the maps and reports of the Site Survey Section of the Forestry Commission. Although the rocks are greywackes and shales, the overlying drifts and tills apparently derived from them are reddish brown in colour. The soils have been placed provisionally in the Ettrick Association as being analogous to the 'red' Ettrick Association soils described in the Kelso and Lauder areas of east Scotland.

Special Surveys

A9 Trunk Road. Further site investigations have been undertaken at the request of the Scottish Development Department. Collaboration has been continued with the consulting engineers on two projects (a) further examination of the Dalmagarry-Bogbain section (b) an initial site investigation of the approved line for the Avielochan-Slochd section.

(a) Twenty-eight pits were dug by a Fiat S90 Tracked excavator. Two of these were examined to a depth of 12 metres, the remainder varying from 2 to 8 metres. Of particular note was the occurrence, to below 12 metres, of a strongly developed platy structure associated with an indurated schist-derived till belonging to the Strichen Association. Such till was frequently found to be interstratified with bedded gravelly loamy fine sand, especially in the top 3 metres. Under wet conditions this bedded material displayed a marked thixotropic quality, flowing rapidly from discrete pockets and causing severe slumping of the overlying horizons.

(b) Approximately 40 pits, ranging in depth from 2 to 11 metres have been located for examination.

Campbeltown. A soil and land use capability study of the Campbeltown area was carried out at the request of the Planning Department of the Argyll and Bute District, Strathclyde Region. Approximately 45 km² were surveyed on a scale of 1:25 000 in the low ground extending from Campbeltown to Machrihanish and northwards along the coast from Campbeltown to Peninver. Soils provisionally correlated with the Balrownie, Auchenblae and Boyndie Associations were found together with alluvial soils and peat. Drift containing Old Red Sandstone rocks from the Firth of Clyde incorporated schists and gneiss derived from local rocks as an ice-sheet flowed from east to west across the Kintyre peninsula. The drift cover was subsequently re-worked by both beach and alluvial processes to give extensive areas of red gravels and alluvium. Marshy hollows accumulated peat and peaty alluvial soils. All the soils found could be correlated with existing

series, but one new soil complex, consisting of Balrownie-type till and outcrops of schist and gneiss was extensive on the higher fringes of the area and has been provisionally named the Baraskomill complex.

Kirkconnel and Kelloholm. Soil and land use capability maps, on the scale of 1:10 000, of the 6 km² in Upper Nithsdale have been prepared at the request of the Dumfries and Galloway Regional Council.

Crichton Royal Farm. A survey, on the scale of 1:2 500, of the soils of Crichton Royal Farm has been made at the request of the West of Scotland Agricultural College.

Dumfries and Galloway Region. A land use capability map of the region, on the scale of 1:250 000, has been prepared at the request of the Regional Council.

Borders Region. A land use capability map of the region, on the scale of 1:250 000, has been prepared at the request of the Regional Council.

Vegetation Surveys

A second draft of the monograph on the Plant Communities of the Lowlands and Southern Uplands of Scotland has been completed and awaits final approval for publication. The bulletin relating to the vegetation map of the Nairn and Cawdor district has been completed. The vegetation map of the district has now been printed locally in Aberdeen. The account of the vegetation of Sheet 39 (Stirling) is ready for inclusion in the Soils memoir of the area.

Recording of the vegetation, by plant sociological methods, of the mainland areas of Sheets 51 (Coll) and 52 (Tobermory) was started in May. The island of Hoy and the Mainland of Orkney (Sheets 117, 119 and 120) were visited in June and recording of the vegetation undertaken. The recording of the vegetation of Sheet 47 (Crieff) was completed in July.

During the last week of August and the first week of September the vegetation of a broad transect from the summit of Cairnsmore of Fleet to Creetown in S.W. Scotland was recorded. This initiates the second vegetation map undertaken by the Soil Survey in Scotland. It will entail recording by plant sociological methods all the important vegetation units in the area and subsequent mapping of the vegetation at a scale of 1:10 000.

A paper on Erico-Sphagnetum magellanici, *J. J. Moore* (1964) has been published[49] and another on a North Atlantic race of Caricetum chorodorrhizae, *Paul et Lutz* (1941), a rare community in north Scotland, has been submitted for publication[102].

Soil Micromorphology

With the transfer of the Micromorphology Section to the new Soil Survey premises in Craigiebuckler House, considerable time has been required to reorganize the laboratories and set up equipment. This has led to a drop in the intake of soil samples and thin section preparation. However, with organization of the new premises virtually complete, facilities for micromorphological work are considerably improved and soil thin

section preparation has been divided into three distinct phases—sample receipt and preparation; freeze drying and vacuum impregnation; and thin section preparation. A separate microscope room with slide storage facilities is now available.

Examination of the micromorphology of brown forest soils has continued and a draft account is in preparation.

During the year, approximately 150 soil thin sections have been prepared, and 12 monoliths have been added to the collection.

Eight members of the committee of the International Working Group on Soil Micromorphology visited the Department.

A paper describing and discussing the micromorphology of three soil profiles from Elephant Island (Antarctica) has been prepared for submission to the British Antarctic Survey Bulletin.

A paper on the genesis of alpine and upland soils in the British Isles[50] has been published and another on some genetic characteristics of the freely drained soils of the Ettrick Association in East Scotland[103] has been submitted for publication. A paper on soil and archaeology in Scotland has been published[51]. 804

Other Survey Work

Collaboration and consultation has continued with the Department of Agriculture and Fisheries for Scotland and with the three Scottish Colleges of Agriculture, particularly on problems relating to field drainage and in the final preparation of land use capability maps. A number of talks have been given and field excursions led to demonstrate soils in areas ranging from Caithness to Dumfriesshire.

Information and soil samples have been provided for a West of Scotland Agricultural College training course for DAFS and College staff and assistance given in the conduct of the course. Similar assistance has been given to a project to build up trace element information for soil series in the West College area. A contribution has been made to the Report on the Slamannan Drainage Project[104] and a paper published on soils developed on Carboniferous sediments[52].

Collaboration with the East of Scotland College of Agriculture has continued on the Strath Braan Drainage Project and the monitoring programmes at Little Findowrie and Ballinloan.

Liaison has been maintained with the Forestry Commission, the Nature Conservancy Council, the Department of the Environment, the Hill Farming Research Organisation, the Scottish Horticultural Research Institute, the Highlands and Islands Development Board, the British Gas Corporation and with other departments of the Institute.

Many requests for soils information have been dealt with, from planning and engineering departments of regional and district authorities, colleges, schools and university departments as well as interested individuals. The outline 1:25 000 soil maps have been much in demand and appear to be serving a useful purpose. Advice has been given on the soils of several archaeological sites.

In collaboration with the Institute's Information Officer, an exhibit illustrating soil survey and land use capability classification was staged at the Symposium on Native Pinewoods sponsored by the Nature Conservancy Council at Aviemore. A similar exhibit, with emphasis on moorland soils, was provided for the Institute of Biology's Symposium on Heather Moorland held in Aberdeen; a paper on relevant soils was also presented.

A chapter on the geomorphology and soils of Mull has been written for a book on the Flora of Mull[105].

Sections for the Soil Survey Handbook have been written on the photography of soils and associated landscape[106]; soil bulk density measurements in the field by γ-ray transmission[107] and soil temperatures[108].

801, 802, 804

Maps, Memoirs and Cartography

The 1 inch Soil Survey maps covering parts of Sheets 35, 36, 43, 44, 51 and 52 (Island of Mull) and combined Sheet 24/32 (Peebles/Edinburgh) together with 1 inch Land Use Capability maps for combined Sheet 1/2/3/4 (Kirkmaiden/Whithorn/Stranraer/Wigtown) and combined Sheet 24/32 (Peebles/Edinburgh) have been published. Colour proofs of the Soil Survey maps for combined Sheet 40/41 (Kinross/Elie) and combined Sheet 84 and part of 94 (Nairn/Cromarty) have been corrected and returned to Ordnance Survey for final printing.

Scribed negatives and colour models of the Land Use Capability maps for combined Sheet 40/41 (Kinross/Elie) and combined Sheet 66/67 (Banchory/Stonehaven) have been submitted to Ordnance Survey for colour proofing. The negative of the Land Use Capability map of combined sheets 33/34 (Haddington/Eyemouth) has been scribed and the colour model is being prepared.

The final printing of the Nairn/Cawdor Vegetation map on the 1:25 000 scale has been completed and work is proceeding on its accompanying bulletin.

Seven sheets have been added to the uncoloured 1:25 000 scale Soil Survey field sheets for restricted circulation, bringing the total to 122. The recent additions are five from Fife Region, one from Borders Region and one from Highland Region.

The following limited circulation maps have been prepared: provisional Land Use Capability maps of Borders Region on 1:250 000 scale, of Ardnamurchan and Morvern on 1:63 360 scale and of the Campbeltown Area on 1:25 000 scale; a provisional soil map of the Campbeltown Area on 1:25 000 scale.

The page proofs of the memoir for Sheets 48/49 (Perth/Arbroath) have been corrected and the memoir is now being printed[109]. 801

SOILS OF THE COUNTRY ROUND AIRDRIE

The survey of the soils of Sheet 31 has now been completed and a preliminary summary of the findings is given below.

The area covers about 1080 km^2 (416 square miles) of the Motherwell,

Monklands, Cumbernauld, Strathkelvin, Stirling, Falkirk and West Lothian Districts. Four physiographic regions can be delineated, as shown in diagram.

1. The Campsie and Kilsyth Hills to the north and west
2. The Lower Forth Valley
3. The Carboniferous Lowlands, comprising the Stirlingshire Drift Plain, Kilsyth Gap, Cadder Lowlands and Clydesdale
4. The Slamannan Plateau and North Lanarkshire Uplands.

Geology

The solid rocks underlying the area are mainly Carboniferous sediments but in the north-west the Campsie and Kilsyth Hills consist of basalts and dolerites in the form of dykes and sills. These volcanic outcrops are of mildly rippled synclinal form with a regional eastward dip, the summits rising from 180 m to above 550 m in Meikle Bin and Holehead near the heart of the outcrop.

In the Lower Forth Valley post-glacial fluctuations in sea-level have resulted in the formation of extensive raised beach deposits and spreads of estuarine alluvium ranging in altitude from sea-level to about 40 m.

To the south of this area, the land rises fairly rapidly to the Slamannan Plateau and the North Lanarkshire Uplands. This is a gently undulating area ranging in altitude from 105 m to 290 m with occasional intrusions of quartz dolerite giving rise to areas of less uniform topography.

The Cadder Lowlands, Clydesdale and the Kilsyth Gap have a similar topography to the Slamannan plateau; the main differences are due to altitude (60-150 m) and a more equable climate.

Glaciation over the whole area and subsequent marine erosion and deposition in the Forth Valley has left little of the ground without a drift covering. This results in a great variety of soil parent materials, including tills, moraines and fluvioglacial deposits.

The geological succession is:

Recent		Peat and alluvium
Post-glacial		Low raised beach deposits
Pleistocene		Solifluction deposits, fluvioglacial sands and gravels, till and high raised beach deposits
Carboniferous		
	Upper	Coal Measures: Passage Group: sandstones, mudstones, shales and coals
	Lower	Lower Limestone Group: sandstones, limestones, shales Calciferous Sandstone Measures: sandstones, mudstones, oil shales, lavas and tuffs.

Climate

The climate of the area is strongly influenced by the W.N.W.-E.S.E. trend of the Forth lowlands which ensures that strong airmass influences from either west or east may temporarily prevail at any season. The westerly airflow is more evident in the autumn when the area is influenced by the passage of well developed Atlantic depressions. These winds carry a heavy rainfall to the north-west of the area where average rainfall is in

excess of 1800 mm. This drops to 1145 mm on the Slamannan Plateau and 890-1015 mm around Glasgow, whilst along the Forth estuary, near Grangemouth, values decline to less than 800 mm. January is the wettest month with the driest period from April to June.

Over much of the cool, wet foothill and upland area, there is a surplus of rainfall over evapotranspiration in every month of the year. In the eastern warm, rather dry lowlands, a soil moisture deficit approaching 50 mm frequently occurs by early July and, despite its progressive elimination during the wetter summer months, this deficit can create problems for agriculture.

In the lower Forth Valley the mean monthly maximum temperatures rise by some 14°C from 5·8 to 19°C between January and July, which is at least as rapidly as anywhere in Scotland. In the surrounding hills and valleys the temperature is modified by relief with a depression of summer maxima. Snowfalls are most frequent in the first quarter of the year with snow lying for 20-30 days on the Campsies. Bleak conditions are also apparent at relatively low elevations in the foothills, about 70 air frosts per year being recorded with a high frequency during the critical growing period in April and May.

During late spring and early summer, a 'haar' moving inland from the North Sea lowers both sunshine duration and maximum temperatures in the coastal lowlands at this time of year.

Soils

Forty-three soil series and five soil complexes have been mapped and are grouped into the following twelve soil associations:

Association	*Parent Material*
Bargour	Till mainly from Upper (Barren) Coal Measures sandstone
Carbrook	Estuarine High Raised Beach silts and clays
Darleith	Basic igneous rocks of fine and medium texture and drived drifts
Darvel	Fluvioglacial sand and gravel mainly from Carboniferous sediments
Dreghorn	Raised beach sand mainly from Carboniferous sediments
Drongan	Till mainly from Upper Carboniferous marls and shales
Giffnock	Drift mainly from Carboniferous sandstones
Kilmarnock	Till from Lower Carboniferous sediments and basic igneous rocks
Kirktonmoor	Moraine debris from basaltic lavas and ash of Carboniferous age
Rowanhill	Drift from Carboniferous shales, sandstones, cementstones and coals
Sorn	Till from Lower Carboniferous and Old Red Sandstone sediments and lavas
Stirling	Estuarine Low Raised Beach silts and clays

In addition the following miscellaneous soils have been mapped:

Blanket Peat
Basin Peat
Peat alluvium complex
Alluvium
Saltings
Restored ground and reinstated areas of opencast mining
Mixed bottom land

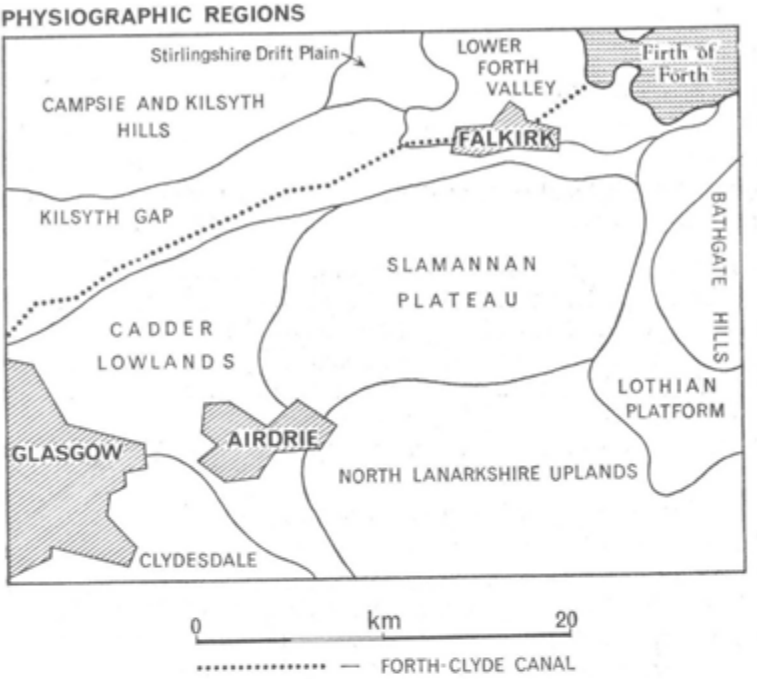
The alluvium has been subdivided on a textural and drainage basis, but where the soil pattern was complex the alluvium was not differentiated. A high rainfall of 1500 mm (60″) per annum results in the extensive development of Blanket Peat on the Campsie and Kilsyth Hills where, on concave sites, it frequently exceeds 100 cm and on the more exposed summits is often eroded. The Blanket Peat and Basin Peat have been divided where practicable into two categories according to depth, *i.e.* 50-100 cm and >100 cm.

The major soil groups of the area are shown in the diagram.

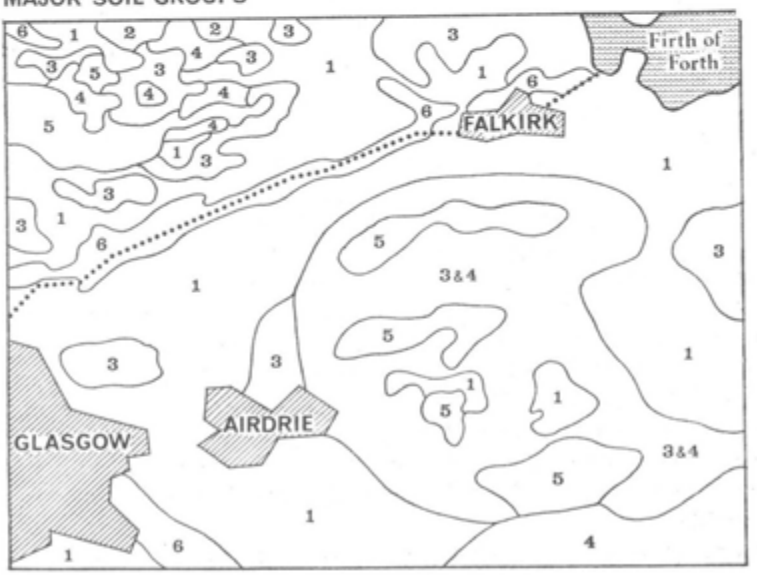
The most extensive group of soils, the Rowanhill Association, accounting for about 36 per cent of the area, comprises seven soil series and two soil complexes, developed on parent materials derived from Carboniferous shales, sandstones, cementstones and coals. The dominant soil, the Rowanhill series, a poorly drained surface-water gley soil, occupies some 18 per cent of the map and is mainly confined to the Slamannan Plateau and North Lanarkshire Uplands. It has a dark grey to grey-brown A horizon of loam or sandy clay loam texture. The B horizon has a grey colour with abundant ferruginous mottles. The texture is usually a clay loam, but where the shale content is high then clay may be found. The structure is coarse prismatic with grey sand-coated ped faces, and this coarse structure and high clay content give the soil a very impermeable subsoil with a hydraulic conductivity of less than 3 cm/day. Due to the impermeable nature of the subsoil the soil is saturated to within 40 cm depth for 200-350 days most years. The soil reaction is generally slightly acid, pH 5·5-6·5, changing little down the profile; below two metres the till is often weakly calcareous. The degree of base saturation and exchangeable Ca content are high where lime has been regularly applied, whilst the total phosphorus values are moderate. On the wetter colder areas and close to the peat mosses, the peaty gley soil, Glaisnock series, has been mapped. A mineralized phase of this series has been distinguished, having in the A horizon a high percentage carbon content and consequently a low bulk density and dark colour. The necessity for separating these soils from the Rowanhill series is that they remain wet for a longer period and hence give greater cultivation problems.

The Caprington series, an imperfectly drained surface-water gley, accounts for some 9 per cent of the area; it occurs mainly on the lower areas and consequently under a lower annual rainfall and warmer climate. Its chemical properties are very similar to those of the Rowanhill series, the

PHYSIOGRAPHIC REGIONS



MAJOR SOIL GROUPS



1 Brown Forest Soils and associated gleys
2 Podzols
3 Non Calcareous Gleys
4 Peaty Gleys
5 Peat
6 Alluvium

main difference being a lower humus content in the A horizon. The soil matrix colour is browner than that of the Rowanhill series and the structure is often less coarse. Being better drained in consequence and with its more favourable climatic conditions and higher rate of evapotranspiration, this soil presents fewer management problems.

The Macmerry series is an imperfectly drained soil with partially sorted surface horizons of sandy loam texture merging into sandy clay loam or clay loam with depth. The chemical properties are similar to the related Rowanhill and Caprington soils, but the Macmerry series differs from the Caprington series, in that it is coarser textured and finer structured in both the A and B horizons. It is seldom saturated to within 40 cm from the surface for more than three months over the winter period, but the fine textured subsoil remains moist for much of the growing season and helps to prevent any serious moisture deficit in the topsoil, making this soil one of the most valuable in the area.

The Greenside series, a freely drained brown forest soil, occurs to a limited extent, generally where the drift is thin. The principal morphological features are a dark brown A horizon with a blocky structure and a sandy loam texture throughout. This soil is of limited agricultural importance.

The soils of the Darvel Association account for about 4 per cent of the area. They occur on the fluvioglacial deposits on the lower-lying land of the Kilsyth Gap, around Glasgow to the west and Linlithgow in the east and also on the Stirlingshire Drift Plain. The dominant soil, the Darvel series, a freely drained brown forest soil, has a dark brown A horizon with a sandy loam texture and a very weak crumb or fine blocky structure. The subsoil becomes coarser textured with depth and has single grain structure in the C horizon. Two phases have been mapped: a gravelly phase, where the stone content exceeds about 10 per cent—affecting cultivation and seed bed preparation, and a non-gravelly phase, where, although there are some stones present, they are not large or numerous enough to interfere with cultivation. The Darvel series has a medium cation exchange capacity decreasing with depth to low values (about 5-6 me/100g) and a medium P_2O_5 content (200-300 mg/100g) decreasing with depth. A humus iron podzol, an imperfectly drained brown forest soil and a poorly drained gley soil have also been mapped in this association, but are of minor extent.

The soils of the Giffnock Association occur on the Stirlingshire Drift Plain, the Slamannan Plateau and the North Lanarkshire Uplands, where a high content of sandstone is present in the drift. The most common soil is the Aberdona series, an imperfectly drained surface-water gley. The principal morphological features are a dark greyish brown A horizon of sandy loam texture overlying a mottled brown to pale brown sandy clay loam B horizon. The B horizon has a moderately developed subangular blocky structure. The parent material in this series is often underlain by a finer textured material, similar to the till of the Rowanhill Association, at about 1 m from the surface. The Aberdona series has a medium cation exchange capacity throughout, a high base saturation (60-90%) and a slightly acid reaction down the profile. The Giffnock series, the poorly

drained surface-water gley, differs from the Aberdona series in having a coarse-structured B horizon.

The Scaurs series, the peaty gley, has been mapped, together with a mineralized phase, on the higher wetter areas of the North Lanarkshire Uplands. It contains large stones and boulders of coarse textured Carboniferous sandstone which are very evident when ploughing for forestry has taken place, but being soft cause little difficulty. If fragments of these soft sandstones are included in a soil sample they give a misleadingly high sand fraction in a mechanical analysis.

A humus iron podzol, Bath Moor series, has been mapped in areas where the drift cover is very thin and in stony coarse textured drift overlying till at depth. It is characterized by a horizon of friable humus overlying a sandy eluviated horizon which in turn overlies a black or very dark brown Bh horizon of sandy loam texture; beneath this humose layer is a horizon with a strong brown colour and sandy loam texture, passing into a stony C horizon or rock. It is generally very acid, but where the drift is thicker and the topography more even, liming has raised the pH to 5·5-6·0.

The basic lavas of the Campsie, Kilsyth and Bathgate Hills give rise to a fairly uniform soil parent material on which are developed soils of the Darleith Association, accounting for about 9 per cent of the area and comprising twelve soil series and one soil complex. The Darleith series is predominant in the association, especially on steep slopes. It is a freely drained brown forest soil with a dark brown stony fine sandy loam A horizon over a very fine sandy or silty loam B horizon with a slightly redder hue. The C horizon, when present, is often of high bulk density with properties of a fragipan. The base status is high throughout the profile (60-90%), cation exchange capacity is medium as are the levels of total P_2O_5 (180-300 mg/100g). The chemical properties of the A horizon tend to vary with management and where liming has been carried out a pH of 5·9-6·5 is common. The Dunlop series, an imperfectly drained brown forest soil, is found on lower and middle slopes of the Kilsyth Hills.

Poorly drained gley soils, Amlaird series, are frequent in hollows or on gentle slopes below spring lines. In these situations, a combination of the slow permeability of the clayey till and high rainfall tends to increase the drainage problem which is accentuated by the lack of field drains.

On the higher slopes of the hills above 300 m, where the topography is frequently a series of shallow steps, the soil pattern is one of peaty podzols with iron pan, Baidland series, or peaty brown soils, Tomtain series, under *Calluna* or *Nardus* respectively. Peaty gley soils, Myres series, are common on the wet, rushy, gentler slopes with peat widespread on the shelves. The edges of each lava scarp normally have rock outcrops around which are developed brown and peaty rankers mapped as the Glenaros and Lecket series. Limited areas of montane humus soil, Holeface series, have been mapped above 500 m on stabilized slopes. Where the drift tends to be thin and rock outcrops and screes are common, the Dalmahoy complex has been used as a mapping unit.

The Low Raised Beach deposits between 3 and 15 m above sea level, occurring along the north-eastern edge of the sheet to beyond Grangemouth,

form the parent material of the Stirling Association which accounts for 2 per cent of the area and includes some very productive agricultural land.

The parent material of the soil is very fine textured and varies between a silty clay and a clayey silt, the clay content sometimes being as high as 70 per cent or the silt content as much as 60 per cent. The dominant Stirling series is a poorly drained ground water gley soil which has many of the characteristics of a surface-water gley. However, the drainage of the top metre of these soils has been improved by the use of tile drains. When wet the soil is massive, sticky and structureless, but on drying it shrinks and fractures into very coarse prisms which become very hard. The base status is high throughout the profile (60-100%), cation exchange capacity is medium increasing slightly with depth. Levels of total P_2O_5 are medium (200-300 mg/100g) but levels of acetic soluble P_2O_5 tend to be high throughout the profile (>10mg). The pH is slightly acid in the A horizon, but becomes alkaline at depth (7·5-8·5) due to the influence of a high concentration of sea shells at 1 m depth. The soils are responsive to fertilizer treatment, but are difficult to cultivate unless at the correct moisture content and require very careful management.

The High Raised Beach deposits, covering about 2 per cent of the area, are of two types, silts and clays and sands and gravels, both occurring at altitudes ranging from 25 m to 40 m above sea level. The sands and gravels, on which the Dreghorn Association is developed, occur around Stenhousemuir, up slope from the Carse deposits. Dreghorn, the dominant series, is a freely drained brown forest soil of low base status, low cation exchange capacity and a slightly acid pH. The coarse texture precludes continuous cropping on this soil, a grass break being required to build up surface organic matter and prevent the crop suffering from summer drought. The silts and clays which occur on the north side of the High Raised Beach deposits are of limited extent. They have been separated as the Carbrook Association where the dominant series is a poorly drained surface-water gley.

The areas of the Bargour, Drongan, Kilmarnock, Kirktonmoor and Sorn Associations are of only minor extent, each one representing less than 1 per cent of the total area.

Land Use and Agriculture

The majority of the productive arable soils of the area are included in Land Use Capability Class 3 with only limited areas of Class 2 confined to the coarser-textured soils of the sandy raised beaches (Dreghorn series) and the water-worked till (Macmerry series).

The imperfectly drained series of the Giffnock, Rowanhill and Sorn Associations have been included in Class 3ws because of the wetness of these soils at critical times of the year at sowing and harvest. Careful management is needed to ensure minimum damage to soil structure by working these soils only when conditions are suitable. The finer texture and consequent longer periods of wetness of the poorly-drained series of these associations make successful cultivation very difficult and these soils are included in Class 4w.

The most productive of the soils of the Stirling Association are also included in Class 3ws, largely because of the difficulty of producing a seed-bed for crops in this fine-textured soil. This problem of cultivation precludes the growing of root crops on a large scale.

The soils of the Darvel Association are usually stony and associated with a moundy topography. In the drier eastern parts these soils are limited by their low moisture-holding capacity, while in the west the uneven topography and steep slopes cause cultivation and harvesting difficulties. These soils are included in Class 3sg.

Above altitudes of about 150 m on south and west facing slopes and 120 m on north and east facing slopes climatic effects become more pronounced. Consequently soil and site limitations become more severe and soils occurring above these levels are usually included in Class 4.

In the upland areas of the Campsie and Kilsyth Hills, at altitudes from about 180 m to about 500 m, the slopes are too steep and too high for arable cultivation and are kept in permanent pasture. Most soils are included in Class 5 provided the rainfall is <1500 mm. At higher altitudes severe exposure, excessive rainfall and restricted growing season limit the shallow peaty soils and blanket peat deposits to Class 6. Areas of scree and rock outcrop, such as the Campsie scarp features, are included in Class 7.

The wide range of soils which occupy the area have a marked influence on the variety of agricultural enterprises. The most important crop in the area is grass, especially temporary grass which constitutes half of the arable acreage. Not only is this grass produced for consumption by livestock on the farm but it is also an important cash crop when sold as Timothy hay from the Carse farms where yields of four tons per acre are common. Permanent grassland makes a major contribution to livestock production in the area, particularly where the rainfall is high as in west Stirlingshire, on the Slamannan Plateau and the North Lanarkshire Uplands.

The Campsie and Kilsyth Hills are predominantly upland grassland consisting of various combinations of *Agrostis* spp., *Festuca ovina, Festuca rubra, Deschampsia flexuosa, Nardus stricta* and *Molinia caerulea* which supports a sheep stocking rate of about 1·5 per acre.

LIBRARY

The library holds an extensive collection of literature on soil science and related subjects. The service is primarily for members of staff, but loans can be obtained by individuals and institutions, either on direct application or through the inter-library loans schemes. A list of holdings of periodicals is available on request.

High subscription charges again restricted the intake of journals. A revision of existing journal holdings resulted in the cancellation of subscriptions to eight which had changed in character over the years or had increased in cost to such an extent that usage no longer justified the expenditure; twelve new journals were chosen to replace them. One hundred and seven books were added to stock.

Borrowing from other libraries continued to be heavy, involving 997 items during the year. Two hundred and fifty-three requests for loans were received from external bodies.

This year 4488 reprints of staff papers were supplied to individual scientists and institutions all over the world. Lists of available publications are sent out periodically and anyone wishing to receive these should apply to the Librarian. No charge is made for reprints.

PUBLICATIONS

(A) *Published*

1. The removal of organic matter from soil extracts by bromine oxidation. By B. D. Mitchell and B. F. L. Smith. (*J. Soil Sci.*, **25**, 239-241, 1974.)

   Organic matter, extracted from soils during chemical treatments, causes interference in subsequent spectrophotometric determinations of extractable components. A method for the complete removal of the interfering organic matter by treatment of the extract with bromine has been devised and tested.

2. Highways and byways in thermal analysis. By R. C. Mackenzie. (*Analyst, Lond.*, **99**, 900-912, 1974.)

   In the past thermogravimetry and differential thermal analysis have yielded useful information in soil science, from both the mineralogical and the chemical aspects. Recent developments in these techniques are reviewed, with special reference to aspects of analytical chemistry. Resurgence of interest in other less-common thermoanalytical techniques is noted and some forecasts are made regarding developments in the field of thermal analysis as a whole.

3. Further information on peak areas and heats of transition of DTA temperature standards. By R. C. Mackenzie and P. F. S. Ritchie. (*Revue Générale de Thermique*, **159**, 118-222, 1975.)

   The validity of using differential thermal analysis (DTA) for quantitative studies on soils and clays is based on the relationship between peak area on the DTA curve and the energy absorbed or evolved in the reaction. Comparison of results for standard materials used for temperature calibration of DTA equipment (available from the U.S. National Bureau of Standards) and literature values for heats of transition show that the DTA method is reasonably accurate and can be used to check whether values quoted in the literature are suspect.

4. The thermal characteristics of soil minerals and the use of these characteristics in the qualitative and quantitative determination of clay minerals in soils. By R. C. Mackenzie and S. Callière (Paris, France). (pp. 529-571 of *Soil Components. Vol. 2 Inorganic Components.* Edited by J. E. Gieseking. New York: Springer, 1975.)

   An account is given of the general principles of thermogravimetry and differential thermal analysis, the theoretical background of the methods, and the apparatus and experimental techniques employed. The thermal characteristics of each of the mineral groups in the phyllosilicate class are considered in turn with particular reference to the occurrence of these minerals in soils. Non-crystalline and accessory minerals are also briefly discussed. Application of the methods to soil-clay mineralogy is assessed from the viewpoints of interpretation of curves and quantitative determinations. It is concluded that thermal methods have a valuable part to play in soil-clay mineralogy, although for a complete mineralogical analysis of any soil clay all available techniques must be employed.

5. Chemical weathering of some primary rock-forming minerals. By M. J. Wilson. (*Soil Sci.*, **119**, 349-355, 1975.)

   Weathering is a process of fundamental importance in the release of elements of biological importance and in the formation of clay minerals which, to a large extent, determine the physical and chemical properties of soils. Recent ideas and findings relating to the mechanisms and products of weathering of felspars, micas and ferromagnesian minerals in soils are critically reviewed.

6. The classification of silicates and oxides. By R. C. Mackenzie. (pp. 1-25 of *Soil Components. Vol. 2. Inorganic Components.* Edited by J. E. Gieseking. New York: Springer, 1975.)

   A review of the classification of silicates and oxides which commonly occur in soils.

7. Oxides and hydrous oxides of silicon. By B. D. Mitchell. (pp. 395-432 of *Soil Components. Vol 2. Inorganic Components.* Edited by J. E. Gieseking. New York: Springer, 1975.)

A review of the properties and occurrence of the various forms of " free " silica in soils.

8. Preparation and X-ray structure of a trinuclear dinitrogen-bridged complex, *trans*–[$MoCl_4\{(N_2)ReCl(PMe_2Ph)_4\}_2$]. By P. D. G. Cradwick and J. Chatt, R. H. Crabtree and R. L. Richards (ARC Unit of Nitrogen Fixation, University of Sussex, Brighton). (*J. Chem. Soc., Chem. Commun.*, 351-352, 1975.)

   In studies relating to nitrogen fixation by soils, attention is being given to compounds containing molecular nitrogen. The compound *trans*–[$MoCl_4\{(N_2)ReCl(PMe_2Ph)\}_2$] has now been prepared and its structure determined by X-ray diffraction.

9. Heavy minerals. By the late W. A. Mitchell. (pp. 449-480 of *Soil Components. Vol. 2. Inorganic Components.* Edited by J. E. Gieseking. New York: Springer, 1975.)

   The occurrence of heavy minerals in the various rock types and the influence of weathering processes and pedogenesis on their distribution in soils is discussed, with particular reference to the relative stabilities of these minerals under different pedological conditions. Methods used for the separation, indentification and quantitative determination of heavy minerals in soils are described and the interpretation of the analytical results is discussed.

10. On the calculation of one-dimensional X-ray scattering from interstratified material. By P. D. G. Cradwick. (*Clay Miner.*, **10**, 347-356, 1975.)

    Interstratified clay minerals frequently occur in soil but are difficult to identify and interpret in terms of degree of ordering of layers. A previous theoretical treatment has been refined to enable more reliable results to be obtained and is tested for interstratifications of illite and montmorillonite, chlorite and vermiculite, kaolinite and montmorillonite and for dolomite.

11. Iron oxide and clay minerals in some red and yellow podzolic soils from the Sydney Region, New South Wales, Australia. By B. G. Davey, J. D. Russell and M. J. Wilson. (*Geoderma*, **14**, 125-138, 1975.)

    An aluminous goethite with 13-14 mol % substitution of AlOOH for FeOOH occurs in both red and yellow podzolic soils from the Sydney Region of New South Wales and is responsible for the colour of the yellow soils. Hematite is present only in the red soils and masks the colour of the goethite. Clay minerals present in the red podzolic soil developed on Ashfield shale include kaolinite, dickite and interstratified illite-smectite minerals some of which contain well-organized aluminous interlayers. Soils developed on Minchinbury sandstone contain less kaolinite and more of an interstratified illite-smectite which is completely free of aluminous interlayers.

12. Imogolite from New Guinea. By R. L. Parfitt and W. J. McHardy. (*Clays Clay Miner.*, **22**, 269-371, 1974.)

    Imogolite, a hydrous aluminium silicate mineral, has been found to occur in several New Guinea soils including three surface horizons of varying age and a buried A horizon that contains halloysite.

13. Formation of iron oxides by decomposition of iron-phenolic chelates. By W. J. McHardy, the late A. P. Thomson and B. A. Goodman. (*J. Soil Sci.*, **25**, 471-482, 1974.)

    Complexes of phenolic organic compounds with iron can be decomposed in the laboratory, under conditions resembling those in freely and poorly drained soils. The species of ferric oxide precipitated is independent of the nature of the chelating agent in freely drained conditions, but it is dependent on the nature of the phenolic chelating agent in poorly drained conditions. Study of these synthetic compounds and their decomposition in the laboratory may help to elucidate the pedogenic processes involved in the dissolution and transportation of iron in soils.

14. Adsorption of carbon dioxide on goethite (α-FeOOH) surfaces, and its implications for anion adsorption. By J. D. Russell, E. Paterson, A. R. Fraser and V. C. Farmer. (*J. Chem. Soc., Faraday Trans. I*, **71**, 1623-1630, 1975.)

    Iron hydroxides play an important role in adsorption phenomena in soils as they commonly occur not only as discrete minerals but also as surface coatings on other minerals. The surfaces of clean goethite crystals, whether wet or dry,

are shown here to chemisorb carbon dioxide at low pressure. A model of the goethite surface that accounts for carbonate formation, and for the displacement of carbonate by phosphate is proposed.

15. Humus type discrimination from mass spectra by a simplified statistical treatment. By J. M. Bracewell, G. W. Robertson and G. J. M. Stephen. (*J. Soil Sci.*, **26**, 62-65, 1975.)

A simplified calculati-n procedure allows discrimination of humus types in Scottish soils to be obtained with only 13 peak height values from each mass spectrum instead of the 110 previously required. The new method obviates assumptions that were necessary in order to obtain the previous discriminator.

16. Thermal decomposition characteristics of humus horizons from Culbin Forest. By J. M. Bracewell and G. W. Robertson. (*J. Therm. Analysis*, **8**, 117-124, 1975.)

Soils developed on sand at Culbin (Laigh of Moray) Forest, Morayshire, contain humus formed entirely from well-defined vegetational cover. The transformation of the vegetation to humus has been investigated by pyrolysis in vacuum combined with mass spectrometry and by differential thermal analysis in oxygen, and appears to be the result of two separate humification processes. The humus in the underlying sand has the characteristics of translocated humus in freely drained soils.

17. Effect of water table level on nitrogen mineralization in peat. By B. L. Williams. (*Forestry*, **47**, 195-202, 1974.)

Lowering the water table level to 18 cm significantly decreases the amount of plant-available nitrogen, measured by anaerobic incubation, in samples of peat cut from the surface horizon at an experimental drainage site in Inchnacardoch Forest, Inverness-shire. Further lowering of the water table reverses the position, mineral nitrogen increasing significantly at least to a water table depth of 34 cm; the position regarding samples incubated under aerobic conditions is more complex but can be explained on the basis of samples containing a mixture of aerated and non-aerated material.

18. Trace element problems on Scottish soils. By R. L. Mitchell. (*Neth. J. agric. Sci.*, **22**, 295-304, 1974.)

A brief review of work on the investigation of trace element problems in Scotland during the past 40 years.

19. A triple-flow gas-sheathed D.C. arc for spectrochemical analysis. By H. K. El-Kholy, J. C. Burridge and R. O. Scott. (*Analytica Chim. Acta*, **74**, 247-252, 1975.)

A gas-sheathed d.c. carbon arc using currents up to 20 A in an argon-oxygen atmosphere and suitable for the analysis of soils and rocks is described. The anode is sheathed by two gas streams from a twin-jet while a third gas stream, confined around the cathode counter-electrode by a silica tube, stabilizes the arc column. Trace element limits of detection are better than can normally be obtained with a cathode-layer arc in air.

20. Lithium, sodium, potassium, rubidium and cesium. By A. M. Ure and R. L. Mitchell. (pp. 1-32 of *Flame Emission and Atomic Absorption Spectrometry. Vol. 3*. Edited by J. A. Dean and T. C. Rains. New York: Dekker, 1975.)
A discussion of the relative merits of the different flame techniques that can be employed for the determination of the alkali metals.

21. The determination of mercury by non-flame atomic absorption and fluorescence spectrometry: a review. By A. M. Ure. (*Analytica Chim. Acta*, **76**, 1-26, 1975.)
Analytical aspects of the determination of mercury by non-flame atomic absorption and fluorescence are comprehensively reviewed. References to applications of these techniques are appended.

22. The characterization of soil minerals by infrared spectroscopy. By V. C. Farmer and F. Palmieri. (pp. 573-670 of *Soil Components. Vol. 2. Inorganic Components.* Edited by J. E. Gieseking. New York: Springer, 1975.)

A review of the application of infrared spectrometry to the identification of mineral species, and to the study of the structure and surface properties of minerals, with particular reference to the clay fraction of soils. A bibliography of infrared spectra of minerals is included (613 references).

23. The correlation of site symmetry species with crystallographic point group species. By V. C. Farmer. (*Spectrochim. Acta*, **31A**, 1303-1305, 1975.)

A set of tables that simplify the analysis of the vibrations of minerals and other inorganic compounds is described. The tables predict, for any compound of known structure, the maximum number of vibrations that can be detected in infrared and Raman spectra, and also indicate the nature of these vibrations and the atoms involved.

24. Comment on "Spectroscopie infra-rouge de quelques acides humiques" by J. R. Bailley. By J. D. Russell and H. A. Anderson. (*Pl. Soil*, **41**, 695-696, 1974.)

Errors in the interpretation of infrared absorption spectra of humic acid fractions arise from contamination of these fractions by inorganic compounds such as bicarbonate and sulphate salts, and silica gel.

25. The occurrence of aphid wax in peat. By R. E. Wheatley M. P. Greaves and J. D. Russell. (*Soil Biol. Biochem.*, **7**, 35-38, 1975.)

Small white aggregates having the appearance of fungal colonies have frequently been observed in peat. It has been shown that they are composed of wax fibres secreted by the aphid *Colopha compressa* (Koch) which colonizes the roots of cotton grass. This aphid species has not previously been reported in Scotland.

26. Acetyl groups in cell-wall preparations from higher plants. By J. S. D. Bacon, A. H. Gordon, E. Jane Morris (Rowett Research Institute, Aberdeen) and V. C. Farmer. (*Biochem. J.*, **149**, 485-487, 1975.)

The cell wall polysaccharides of grasses and other higher plants are shown to carry acetyl groups, which could confer a degree of resistance to digestion by grazing animals, or to enzymic breakdown in soil. Infrared spectroscopy is a rapid and convenient method for identifying acetyl in plant material.

27. Decomposition of soil polysaccharide. By M. V. Cheshire, M. P. Greaves and C. M. Mundie. (*J. Soil Sci.*, **25**, 483-498, 1974.)

When polysaccharide, isolated from soil by extraction with alkali, is used as a substrate in soil incubation, perfusion and suspension experiments carbohydrate equivalent to 70-100 per cent of the polysaccharide is decomposed within 32 weeks, depending on the amount added. There is little change in the carbohydrate content of unamended soil in comparable conditions. It is concluded that the persistence of naturally occurring polysaccharide in soils is a result of its relationship with other soil components and not of any intrinsic biological stability.

28. The microbial degradation of soil polysaccharide in soil. By M. V. Cheshire, M. P. Greaves and C. M. Mundie. (pp. 147-156 of *Proc. I internat. Colloq. on Biodegradation and Humification, Nancy, France*, 1974.)

Radioactively labelled soil polysaccharide was obtained by extracting soil which had been incubated with ^{14}C-glucose. When the polysaccharide was incubated with soil much of it was readily decomposed. This result confirms those obtained with non-radioactive soil polysaccharide and suggests that the stability of the indigenous polysaccharide is not attributable solely to a resistant structure.

29. Soil polysaccharides and carbohydrate phosphates. By M. V. Cheshire and G. Anderson. (*Soil Sci.*, **119**, 356-362, 1975.)

An appraisal of recent developments in the study of the polysaccharides and carbohydrate phosphates present in soil with particular regard to their origin, structure and stability.

30. Some effects of analogues of uracil on cell elongation and wall metabolism in excised pea root segments. By D. Vaughan and Evelyn Cusens. (*Planta, Berl.*, **122**, 227-238, 1975.)

Soil organic matter stimulates the growth of plant roots but how it does so is not clear. When plant roots are growing the individual cells near the root tip increase in length, but as their cell walls become more rigid the cells cease to elongate. The effect of substances related to nucleic acids and amino acids on changes in the composition of cell-wall proteins has been studied in an attempt to explain part of the mechanism.

31. The effect of salicylic acid on the growth of *Lemna gibba*. By P. C. DeKock, Flora B. Grabowska and Alison M. Innes (University of Aberdeen). (*Ann. Bot.*, **38**, 903-908, 1974.)

    Iron salicylate added to duckweed in sterile culture causes distortion of growth when the growth medium contains the ammonium ion. The effect is abolished if nitrate is present in the medium. As certain soil bacteria produce salicylic acid, this may be a factor in soils which affects plant growth.

32. Cortical cell fluxes and transport to the stele in excised root segments of *Allium cepa* L. I. Potassium, sodium and chloride. By A. E. S. Macklon. (*Planta, Berl.*, **122**, 109-130, 1975.)

    The uptake and loss of nutrient ions by onion root segments have been examined using radioactive isotopes. The results showed that potassium, sodium and chloride ions are all absorbed actively, by mechanisms dependent on metabolic processes in the root cells, rather than by diffusion. Estimation of transport within the root segment showed that all three nutrients enter the root conducting tissue, although sodium is prevented from reaching the leaves of the plant.

33. Cortical cell fluxes and transport to the stele in excised root segments of *Allium cepa* L. II. Calcium. By A. E. S. Macklon. (*Planta, Berl.*, **122**, 131-141, 1975.)
    The uptake and loss of calcium by onion root segments have been examined using a radioactive isotope. In contrast to potassium and sodium, which were shown in an earlier report to be actively accumulated by the root cells, it was found that calcium entered the cells by passive diffusion down an electrochemical diffusion gradient. However, calcium was maintained at less than equilibrium concentration in the root by an outwardly directed metabolic pump.

34. Effects of temperature and chlorpropham on the storage of the yam. By A. O. Olorunda and A. D. McKelvie (School of Agriculture, Aberdeen) and A. E. S. Macklon. (*J. Sci. Fd Agric.*, **25**, 1233-1238, 1974.)

    Chlorpropham, a sprouting inhibitor effective in extending the storage life of potatoes, brings about no significant improvement in the keeping qualities of yams. Cool storage (15°C) is more effective, but exposure to temperatures below about 10°C leads to chilling injury, an early indication of which is a marked increase in the permeability of the cell membranes.

35. Light-enhanced chloride uptake by wheat laminae: a comparison of chopped and vacuum infiltrated tissue. By I. R. MacDonald and A. E. S. Macklon. (*Plant Physiol.*, **56**, 105-108 1975.)

    Although plant nutrition normally occurs *via* the root, the cells in the leaf have an equal ability for absorbing ions. In addition leaf cells have an alternative energy source by way of photochemical reactions. These features together with the increasing use of foliar sprays contribute to the importance of leaf tissue in ion absorption studies. Some of the difficulties inherent in the methods currently used for studying ion uptake by leaf tissue are examined and the existence of a light-stimulated uptake of Cl^- is established.

36. Effect of vacuum infiltration on photosynthetic gas exchange in leaf tissue. By I. R. MacDonald. (*Plant Physiol.*, **56**, 109-112, 1974.)

    Light increases the rate of ion uptake by leaf tissue suggesting a link with photosynthesis or a partial reaction thereof. The photosynthetic rate of leaf tissue of wheat, barley, bean and duckweed was estimated manometrically by measuring both O_2 evolution and $^{14}CO_2$ fixation. Both methods gave good agreement with values determined under field conditions. Leaf tissue pretreated as for ion uptake studies by vacuum infiltration or chopping gave negligible photosynthetic gas exchange. The significance of this finding in relation to photosynthetic studies is discussed.

37. A rapid micromethod for estimating bacterial and protozoan populations in soil. By J. F. Darbyshire, R. E. Wheatley, M. P. Greaves and R. H. E. Inkson. (*Revue Ecol. Biol. Sol*, **11**, 465-475, 1975.) No reprints.

    A rapid method for estimating the populations of soil protozoa and bacteria in soil or peat is described. This micromethod represents a great economy of time, materials and incubator space compared with existing methods. It should now be practicable to increase the frequency and reliability of microbial population estimates in soil or peat.

38. Soil protozoa—animalcules of the subterranean microenvironment. By J. F. Darbyshire. (pp. 147-163 of *Soil Microbiology*. Edited by N. Walker. London: Butterworths, 1975.) No reprints.

Soil protozoa are discussed in relation to the soil environment at the microscopical level or microenvironment. This discussion is prefaced by a brief account of the origins and early development of soil protozoology.

39. Fungicidal effects of the fumigant dazomet on sclerotia of *Sclerotinia sclerotiorum* in soil. By D. Jones. (*Trans. Br. mycol. Soc.*, **63**, 249-254, 1974.)

Dazomet, a chemical fumigant which in contact with moist soil releases methyl isothiocyanate, proved effective in killing sclerotia of the phytopathogenic fungus, *Sclerotinia sclerotiorum*, over a range of temperatures. Its action on sclerotia, from agar plate cultures and collected from soil and agricultural crops in N.E. Scotland, was compared with those of nitrolim (60% calcium cyanomide) and dicyandiamide. The latter compounds inhibit germination of sclerotia but do not appear to be as effective as dazomet since many sclerotia subsequently germinate after being transferred to untreated soil.

40. Ultrastructure of the stipe and apothecium of *Sclerotinia sclerotiorum*. By D. Jones. (*Trans. Br. mycol. Soc.*, **63**, 386-389, 1974.)

Sclerotinia sclerotiorum is a ubiquitous soil-borne fungus which can cause considerable losses in certain agricultural crops such as peas, carrots and potatoes. This paper describes the ultrastructure, as revealed in a scanning and a transmission electron microscope, of the fruiting bodies (apothecia) of the fungus, from which are discharged vast numbers of spores capable of causing infection of suspectible plant material.

41. Microbial decomposition of plant roots. By M. P. Greaves and J. F. Darbyshire. (pp. 108-111 of *Proc. I internat. Colloq. on Biodegradation and Humification, Nancy, France*, 1974.)

Microbial decomposition of plant roots is generally assumed to occur during plant senescence. This communication shows that considerable microbial decomposition of cortical and epidermal tissue in the root can occur at all stages of plant growth.

42. Effects of calcium on sprout growth and sub-apical necrosis in Majestic potatoes. By P. W. Dyson and J. Digby (University of York). (*Potato Res.*, **18**, 290-305, 1975.)

When potatoes are sprouted before planting, changes take place which affect the subsequent growth and yield of the crop. These changes, described as physiological ageing, have been shown to be related to the calcium status of the tuber and sprout. In the cultivar Majestic the first symptom of physiological ageing is blackening of a band of tissue just below the sprout apex, and the name sub-apical necrosis is proposed to describe this condition. Frequent small applications of a calcium salt to the sprout tips prevented the onset of sub-apical necrosis under a wide range of experimental conditions.

43. Effects of calcium on sprout growth of ten potato cultivars. By P. W. Dyson and J. Digby (University of York). (*Potato Res.*, **18**, 363-377, 1975.)

Studies on the effect of calcium on physiological ageing were extended to ten of the most important cultivars grown in Britain. Frequent small applications of calcium to sprout tips was effective in arresting the ageing process in all cases and extension of the main sprout continued for several weeks after it had stopped in untreated sprouts. Without added calcium, extension stopped and lateral branches were produced. With Pentland Dell these branches behaved like stolons and produced tubers, confirming the well known serious effects on yield of planting physiologically old tubers of this cultivar.

44. Other organic phosphorus compounds. By G. Anderson. (pp. 305-331 of *Soil Components. Vol I. Organic Components.* Edited by J. E. Gieseking. New York: Springer, 1975.)

An account is given of the isolation and characterization of the organic compounds of phosphorus found in soil, with the exception of the nucleic acids, which are dealt with in a chapter on soil nitrogen. The possible sources of the various compounds are discussed, together with the factors which affect their accumulation or breakdown in the soil. Some of the analytical methods used to measure total organic phosphate are critically assessed.

45. The nature of alkali-soluble soil organic phosphates. By G. Anderson and R. E. Malcolm. (*J. Soil Sci.*, **25**, 282-297, 1974.)

Further studies on the nature of the organically bound phosphorus in Scottish soils have revealed the presence of a number of compounds not previously detected in soils. Some of them are phosphate derivatives of carboxylic acids, while others contain both glycerol and inositol. Details are given of their isolation and some of their properties.

46. Sulfur in soil organic substances. By G. Anderson. (pp. 333-341 of *Soil Components. Vol. 1 Organic Components.* Edited by J. E. Gieseking. New York: Springer, 1975.)

The nature and properties of soil organic sulphur, which constitutes the bulk of the total sulphur in many soils, are discussed. An outline is given of the methods which have been used to measure and characterize organic sulphur, and the sulphur transformations occurring in soils are also described.

47. The effects of pH on adsorption and desorption of potassium in a granitic soil. By N. Z. Varbanova and B. W. Bache. (*J. Sci. Fd Agric.*, **26**, 855-860, 1975.)

Potassium fixation in soils can reduce the efficiency of potassium fertilizers, but may also provide a reserve that is slowly released over a longer period. The effects of soil pH on the adsorption and release of added potassium was studied in laboratory experiments on soil samples that had been maintained in the field at pH values between 3·8 and 7·5. Evidence for potassium fixation, shown by increasing adsorption at longer time periods and incomplete release of the added potassium, was only found in the samples of pH 6·7 and 7·5, and not in those of lower pH.

48. Soluble aluminium and calcium-aluminium exchange in relation to the pH of dilute calcium chloride suspensions of acid soils. By B. W. Bache. (*J. Soil Sci.*, **25**, 320-332, 1974.)

The extent to which the pH values of dilute calcium chloride suspensions of some acid soils can be accounted for by reactions involving soluble aluminium has been examined. The hydrolysis of aluminium ions in solution, whose concentration is governed by calcium-aluminium exchange reactions, was sufficient to explain the pH values of some of the soils. Other soils, particularly those high in organic matter, contained additional sources of hydrogen ions, and these were presumed to arise from the dissociation of organic acids.

49. Erico-Sphagnetum magellanici J. J. Moore (1964) 1968 in the Sullom Voe area, Shetland Islands, Scotland. By E. L. Birse. (*Phytocoenologia*, **2**, 224-228, 1975.)

The plant community of the blanket bog at Sullom Voe, Shetland Islands, is the same vegetation association as is found on the peat of the Scottish mainland. The three sub-associations recorded for the mainland occur in Shetland, but it is the sub-association differentiated by the lichen *Cladonia uncialis* which is by far the most extensive at these northern latitudes. The climate is strongly influenced by weather systems off the Atlantic Ocean and, because of the severe exposure, common heather is maintained in a short condition suitable for grazing.

50. Some aspects of the genesis of alpine and upland soils in the British Isles. By J. C. C. Romans and L. Robertson. (pp. 498-510 of *Proc. IV Working Meeting on Soil Micromorphology, Kingston, Ontario, Canada, 1973.* 1974.)

Attention is drawn to some palaeopedological features which are common to a range of present day soils developed on stable freely drained sites in upland and montane areas, and their interpretation is discussed.

51. Soils and archaeology in Scotland. By J. C. C. Romans and L. Robertson. (*Res. Rep. Counc. Brit. Archaeol.*, **11**, 37-39, 1975.)

Buried soils which have been recorded at a number of archaeological sites are briefly described. Their significance in signposting the history of soil profile development from the Neolithic period onwards is discussed.

52. Soils developed on Carboniferous sediments and their derived drifts in Scotland. By J. M. Ragg. (*Proc. N. Engl. Soils Discuss. Grp*, **10**, 24-28, 1974.)

The relationship of genetic soil group to four types of drift derived from Scottish Carboniferous sediments is discussed. The differences in lithology and

stratigraphy of Carboniferous rocks on either side of the Border is given, followed by a discussion of the importance of lithology as a discriminating criterion in recognizing Soil Associations.

(B) *Awaiting publication at 30th September, 1975*

53. Thermal analysis. By R. C. Mackenzie. (pp. 389-420, *Physicochemical Methods of Mineral Analysis.* Edited by A. W. Nicol. London: Plenum Press.)

54. Instrumentation for thermogravimetry and differential thermal analysis. By R. C. Mackenzie. (To appear in *Thermal Analysis.* Edited by J. P. Redfern. London: Society for Analytical Chemistry: Chemical Society, Analytical Division.)

55. Complementary techniques. By R. C. Mackenzie. (To appear in *Thermogravimetry.* Edited by J. P. Redfern and C. J. Keattch. London: Butterworths.)

56. The crystal structure of aluminium iodate nitrate hexahydrate. By P. D. G. Cradwick and A. S. de Endredy. (*J. Chem. Soc. Dalton Trans.*, **19**, 1926-1929, 1975.)

57. Scanning electron microscope studies of a surface water gley. By W. J. McHardy and A. C. Birnie. (Submitted to *J. Soil Sci.*)

58. Ultrastructure and chemical composition of species in *Mucorales.* By D. Jones, W. J. McHardy and M. J. Wilson. (Submitted to *Trans. Br. mycol. Soc.*)

59. Exchange properties and mineralogy of some soils derived from lavas of Lower Old Red Sandstone age. I. Exchangeable cations. By M. J. Wilson and J. Logan. (Submitted to *Geoderma.*)

60. Exchange properties and mineralogy of some soils derived from lavas of Lower Old Red Sandstone age. II. Mineralogy. By M. J. Wilson. (Submitted to *Geoderma.*)

61. Nickleloan pyroaurite from Leslie, Aberdeenshire. By M. J. Wilson, P. D. G. Cradwick, M. L. Berrow, W. J. McHardy and J. D. Russell. (*Mineral. Mag.*, **40**, 447-451, 1976.)

62. A titanium-rich soil clay. By D. C. Bain. (Submitted to *J. Soil Sci.*)

63. The reaction of fluoride with soils and soil minerals. By K. W. Perrott, B. F. L. Smith and R. H. E. Inkson. (Submitted to *J. Soil Sci.*)

64. A pyrolysis-gas chromatography method for discrimination of soil humus types. By J. M. Bracewell and G. W. Robertson. (Submitted to *J. Soil Sci.*)

65. Pyrolysis-gas chromatography studies on a climosequence of soils in tussock grasslands, New Zealand. By J. M. Bracewell, G. W. Robertson and K. R. Tate. (Submitted to *Geoderma.*)

66. Is maleic hydrazide a pyrimidine or purine analogue? By P. D. G. Cradwick. (*Nature, Lond.*, 258 (5537), 774, 1975.)

67. Evaluation of peatland sites according to their physical and chemical characteristics. By H. G. Miller, R. A. Robertson and B. L. Williams. (pp. 165-175, *Proc. NERC Symp, Peatland Forestry, Edinburgh,* 1973.)

68. Effect of water table height on growth of *Pinus contorta* on deep peat. By R. Boggie and H. G. Miller. (pp. 93-101, *Proc. NERC Symp. Peatland Forestry, Edinburgh,* 1973.)

69. Physical and chemical factors influencing the cation-exchange capacity of peat under field conditions. By B. L. Williams. (pp. 177-185, *Proc. NERC Symp. Peatland Forestry, Edinburgh,* 1973.)

70. A graphical method of comparing regional vegetation succession in Scotland. By S. E. Durno. (Submited to *Scott. Geogr. Mag.*)

71. Growth of *Pinus contorta* at different water table levels in deep blanket peat. By R. Boggie and H. G. Miller. (Submitted to *Forestry.*)

72. Physical and chemical properties of peat. By V. Puustjarvi (Helsinki, Finland) and R. A. Robertson. (pp. 23-83, *Peat in Horticulture.* Edited by D. W. Robinson. London Acad. P., 1975 for Horticulture Education Association.)

73. Effect of nitrogen supply on nutrients in litter fall and crown leaching in a stand of Corsican pine. By H. G. Miller, Jean M. Cooper and J. D. Miller. (Submitted to *J. Appl. Ecol.*)

74. Analysis of needle fall as a means of assessing nitrogen status in pine. By H. G. Miller and J. D. Miller. (Submitted to *Forestry.*)

75. Effect of nitrogen supply on net primary production in Corsican pine. By H. G. Miller and J. D. Miller. (Submitted to *J. Appl. Ecol.*)

76. Effect of nitrogen supply on uptake of nutrients and growth in Corsican pine. By H. G. Miller, J. D. Miller and Olive J. Pauline. (Submitted to *J. Appl. Ecol.*)

77. Confirmation of the surface structures of goethite (α-FeOOH) and phosphated goethite by infrared spectroscopy. By R. L. Parfitt, J. D. Russell and V. C. Farmer. (Submitted to *J. Chem. Soc. Faraday Trans. I.*)

78. Infrared spectroscopy in mineral chemistry. By V. C. Farmer. (To appear in *The Analysis of Minerals by Physical Methods.* Edited by A. Nichol. London: Plenum Press.)

79. The Mössbauer spectrum of a ferrian muscovite and its implications in the assignment of sites in dioctahedral micas. By B. A. Goodman. (*Mineral. Mag.*, **40,** 513-517, 1975.)

80. On the interpretation of the Mössbauer spectra of biotites. By B. A. Goodman. (Submitted to *Am. Miner.*)

81. The bonding of vanadium in complexes with humic acid: an electron paramagnetic resonance study. By B. A. Goodman and M. V. Cheshire. (*Geochim. Cosmochim. Acta.*, **39,** 1711-1713, 1975.)

82. The occurrence of copper-porphyrin complexes in soil humic acids. By B. A. Goodman and M. V. Cheshire. (Submitted to *J. Soil Sci.*)

83. The composition of soil humus. By M. V. Cheshire, B. A. Goodman and C. M. Mundie. (Submitted to *Rep. Welsh Soils Discuss. Grp.*)

84. The effect of temperature on the microbial transformation of ^{14}C glucose during incubation in soil. By M. V. Cheshire, M. P. Greaves and C. M. Mundie. (Submitted to *J. Soil Sci.*)

85. Automated determination of monosaccharides using p-hydroxybenzoic acid hydrazide. By C. M. Mundie, M. V. Cheshire, H. A. Anderson and R. H. E. Inkson. (Submitted to *Analyt. Biochem.*)

86. The growth of wheat plants in humic acid solutions under axenic conditions. By D. Vaughan and D. J. Linehan. (Submitted to *Pl. Soil.*)

87. Effects of some chelating and phenolic substances on the growth of excised pea root segments. By P. C. DeKock and D. Vaughan. (*Planta, Berl.*, **126,** 187-195, 1975.)

88. Some effects of humic acid on cation uptake by parenchyma tissue. By D. Vaughan and I. R. MacDonald. (Submitted to *Soil. Biol. Biochem.*)

89. Metabolic changes associated with calcium deficiency in potato sprouts. By P. C. DeKock, P. W. Dyson, A. Hall and Flora B. Grabowska. (Potato Res., **8,** 573-581, 1975.)

90. Cortical cell fluxes and transport to the stele in excised root segments of *Allium cepa L. III. Magnesium.* By A. E. S. Macklon and A. Sim. (*Planta, Berl.*, **128,** 5-9, 1976.)

91. The effects of storage and chilling temperature on ion absorption, salt retention capacity and respiratory pattern in yam tubers. By A. O. Olorunda (School of Agriculture, Aberdeen) and A. E. S. Macklon. (Submitted to *J. Sci. Fd Agric.*)

92. Energy supply and light enhanced chloride uptake in wheat laminae. By I. R. MacDonald, A. E. S. Macklon and R. W. G. MacLeod. (*Plant Physiol.*, **56,** 699-702, 1975.)

93. Nitrogen fixation by *Azotobacter chroococcum* in the presence of *Colpoda steini.* III. Dissolved oxygen tension in large batch cultures. By J. F. Darbyshire and M. S. Davidson. (Submitted to *Soil Biol. Biochem.*)

94. The aerobic bacterial flora of a raised bog. By R. E. Wheatley, M. P. Greaves and R. H. E. Inkson. (Submitted to *Soil. Biol. Biochem.*)

95. Copper deficiency in plants and effects of copper dressings on crops and herbage. By J. W. S. Reith. (To appear in *Proc. Symp. on Copper in Farming, London, 1975.*)

96. Organic sulphur fractions in Scottish soils. By N. M. Scott and G. Anderson. (Submitted to *J. Sci. Fd Agric.*)

97. Sulphur, carbon and nitrogen contents of organic fractions from acetylacetone extracts of soils. By N. M. Scott and G. Anderson. (Submitted to *J. Soil Sci.*)

98. Sulphate contents and sorption in Scottish soils. By N. M. Scott. (Submitted to *J. Sci. Fd Agric.*)

99. Characterization of mobile aluminium in acid soils. By B. W. Bache and G. S. Sharp. (Submitted to *Geoderma.*)

100. Soluble polymeric hydroxy-aluminium ions in acid soils. By B. W. Bache and G. S. Sharp. (Submitted to *J. Soil Sci.*)

101. The measurement of cation exchange capacity of soils. By B. W. Bache. (Submitted to *J. Sci. Fd Agric.*)

102. A North Atlantic race of Caricetum chordorrhizae Paul et Lutz 1941, a rare community in north Scotland. By E. L. Birse. (Submited to *Mitt.flor. soz. ArbGemein.*)

103. Some genetic characteristics of the freely drained soils of the Ettrick Association in East Scotland. By J. C. C. Romans and L. Robertson. (*Geoderma,* **14,** 297-317, 1975.)

104. Soils. By B. S. Shipley. (To appear as Soils Section of the "Report on the Slamannan Drainage Project." West of Scotland Agricultural College.)

105. Geomorphology and soils (of Mull). By J. S. Bibby. (To appear in *Flora of Mull.* London: British Museum.)

106. The photography of soils and associated landscapes. By J. M. Ragg. (To appear in *Soil Survey Handbook.*)

107. Soil bulk density measurement in the field by the gamma-ray transmission method. By J. M. Ragg. (To appear in *Soil Survey Handbook.*)

108. Soil temperature. By J. M. Ragg. To appear in *Soil Survey Handbook.*)

109. The soils of the country round Perth, Arbroath and Dundee. By D. Laing. (Sheets 48 and 49.) (*Mem. Soil Surv. Gt. Br.* Edinburgh: H.M.S.O., 1976.)

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.

A.R.C. Institutes

Animal Breeding Research Organization	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, Berks, OX12 9JT.
Weed Research Organization	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, KH6 5HL.
Hill Farming Research Organisation	Bush Estate, Penicuik, Midlothian, EH26 0PH.
Macaulay Institute for Soil Research	Craigiebuckler, Aberdeen, AB9 2QJ.
National Institute for Agricultural Engineering (Scottish Station)	Bush Estate, Penicuik. Midlothian, EH26 0PH.
Rowett Research Institute	Bucksburn, Aberdeen, AB2 9SB.
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 Institute	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 2QJ.
Welsh Plant Breeding Station	Plas Gogerddan, Aberystwyth Cardiganshire, SY23 3EB.
Wye College, Department of Hop Research	Ashford, Kent, TN25 5AH.