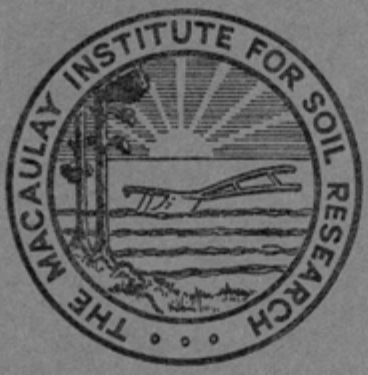
THE MACAULAY INSTITUTE FOR SOIL RESEARCH



FOUNDED 1930

ANNUAL REPORT 1960-1961

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THE MACAULAY INSTITUTE FOR SOIL RESEARCH

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J. C. Bensink (Royal High School of Tropical Agriculture, Deventer, Holland).
Beate Berner (Statens Rästofflaboratorium, Ostmarka, Trondheim, Norway).
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R. A. Chen (Ministry of Agriculture and Lands, Kingston, Jamaica).
M. M. Guha (Rubber Research Institute of Malaya, Kuala Lumpur, Malaya).
A. Dowgiallo (Nencki Institute of Biology, Warsaw, Poland).
M. Dzami (Department of Biochemistry, University of Belgrade, Yugoslavia).
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R. J. Hance (Ministry of Agriculture, Fisheries and Food, London).
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E. V. Robinson (Department of Geology, University of Queensland, Brisbane, Australia).
K. Singh (Colombo Plan Scholar).
N. Velikonja (Institute of Chemistry, University of Zagreb, Yugoslavia).

CONTENTS

INTRODUCTION

Completion of the first phase of the new building and its occupation by the departments of Soil Survey, Spectrochemistry and Biochemistry, by the sections of Physical Chemistry, Soil Mineralogy and Soil Analysis in Pedology and by Library and Administration have made the year a memorable one in the history and development of the Institute. Thanks to commendable organization by the staffs of the departments concerned, particularly in the phasing of transfer of equipment, removal to the new laboratories caused relatively little interruption of work and progress in the research programme has been well maintained. Constructional work on the second phase of the new building, designed to accommodate the departments of Plant Physiology, Microbiology and Soil Fertility, the Peat Ecology and Forest Soils sections of Pedology, the section of Statistics, Chemical Store and Institute Workshop, is proceeding satisfactorily and should be completed next year.

Fruitful contact with educational and research organizations both at home and abroad has been maintained by Institute representation at conferences and meetings bearing on its scientific activities, by provision of facilities for visiting workers from many overseas countries and by a steadily increasing exchange of scientific publications. A member of staff of the department of Soil Survey was seconded to Pakistan during the winter months to assist in the soil survey of Sind and a member of the staff in Plant Physiology was given leave of absence for a year to enable him to accept a U.S. Atomic Energy Commission Fellowship tenable in the University of California, Los Angeles. Various members of staff have again served on technical and advisory committees appointed by the Secretary of State for Scotland and by such bodies as the Department of Agriculture and Fisheries for Scotland, the Ministry of Agriculture, Fisheries and Food, the Agricultural Research Council, the Forestry Commission and the Colonial Office, as well as on other scientific consultative panels and groups.

As in previous years the aim of the research programme has been to obtain from field, greenhouse, pot and laboratory studies information which can be used to maintain and improve soil fertility in its relationships to both crop and animal requirements. With this in view, long-term and short-term studies of both fundamental and applied character have been continued departmentally, interdepartmentally and jointly with other research and educational establishments.

30th September, 1961.

PEDOLOGY

The accommodation occupied in the new building is proving extremely convenient; the facilities are infinitely superior to what was available previously, and the advantages of having laboratories designed for specific purposes are obvious, from the aspects of both quality and quantity of work. Facilities now available for use by all sections of the department, including two sections which will move into Phase 2, are a digestion room, an oven and muffle room, a machine room, a balance room, a soil store with preparation rooms, and a plant milling room. In addition, two rooms, together with a dark room, have been designed for accommodating an electron microscope and its ancillaries.

In the section of Physical Chemistry a completely new differential thermal analysis apparatus, consisting of two control panels capable of operating any of a bank of eight controlled-atmosphere furnaces, has been constructed, and a thermobalance has been installed. A dust-free laboratory has been specially designed for micro and semi-micro chemical analysis; this laboratory is completely self-contained and has access to a small balance room. Two laboratories have been set apart for work on experimental pedology and another for more purely physical investigations.

A Weissenberg X-ray goniometer has been acquired for single-crystal studies in the section of Soil Mineralogy. Two rooms are available for X-ray equipment, and currently two X-ray sets are operating in one of these; it is hoped eventually to fit up at least one additional X-ray set in the other. In the same section one room has been designed for optical work and one for microphotometry, while a small laboratory has been included for chemical preparative work.

One laboratory in the section of Soil Analysis has been reserved for special investigations, as distinct from the standard analysis on soil samples from the department of Soil Survey, which are carried out in the main laboratories of this section.

The worth of these facilities should become increasingly evident in the work of the department over the next few years. In addition, space is such that several research students can be accommodated—a considerable advantage in pursuing certain lines of investigation.

The sections of Peat Ecology and Forest Soils now occupy the accommodation previously shared by the department of Soil Survey with parts of the sections of Soil Analysis and Forest Soils. This move is proving extremely useful in integrating the laboratory work of these two sections, which will in any event be sharing laboratories in Phase 2. Pollen analysis investigations are temporarily being carried out in the rooms designed for the electron microscope; this work will also be transferred to Phase 2 once the laboratories there are ready for occupation.

In the work of the department during the year close collaboration has continued with other departments of the Institute as well as with the Forestry Commission and the Scottish Peat Committee. Samples have been examined on behalf of various overseas territories, the Hill Farming Research Organisation, the Department of Agriculture and Fisheries for Scotland (Peat Section), the North of Scotland Hydro-Electric Board, the Arthur D. Little Research Institute and the Universities of Aberdeen, Durham, Glasgow, Reading and St. Andrews.

Members of staff have attended, *inter alia*, meetings of the Scottish Peat Committee (Moss Survey Group), the Advisory Committee on Forest Research, the British Society of Soil Science, the Nature Conservancy and the Clay Minerals Group of the Mineralogical Society, as well as the Forestry Commission Research Branch Programme Conference. Dr R. C. Mackenzie and Mr W. A. Mitchell attended the Second Conference on Clay Mineralogy and Petrography at Prague, at which, on the invitation of the organizing committee, Dr Mackenzie presented the opening address on the value of different methods in the quantitative determination of minerals in clays[30]. During the conference Dr Mackenzie was presented with a Sixth Centenary Medal of the Charles University in recognition of his contributions to clay mineralogy. Immediately after this conference Dr Mackenzie also attended by invitation a national symposium on thermal analysis organized by the Czechoslovak Academy of Sciences. Dr W. O. Binns attended a symposium on peatland forestry in Belfast, and Mr B. D. Mitchell a symposium on the genesis and synthesis of clay minerals in Paris. In addition, Mr B. D. Mitchell visited the Laboratoire de Chimie Minerale, University of Louvain, Belgium, and the Laboratorium voor Kristallografie, University of Ghent, to study current physico-chemical work on clay minerals, and Dr R. Boggie visited various centres in Ireland to study current peat research there.

PHYSICAL CHEMISTRY

Work during the year has proceeded along the lines previously established, but because of the additional facilities now available the basis has been somewhat broadened.

Separation of Clays. The clay fractions of soils from Soil Survey Sheet 14 (Ayr) were separated for mineralogical examination by differential thermal and X-ray methods. A large proportion of the soil clays isolated during the year were, however, for detailed studies of clay-organic matter complexes and of amorphous aluminosilicates by differential thermal and infrared techniques.

Thermal Analysis. The construction of two differential thermal analysis control panels and a common furnace assembly housing eight controlled-atmosphere furnace units was completed shortly after the section moved into the new building. This apparatus which is now fully operational and producing very satisfactory results incorporates a number of design refinements which were the result of extensive use of controlled-atmosphere differential thermal equipment of high sensitivity[1].

Soil clays from south-west Scotland examined under controlled-atmosphere conditions showed the normal mineral assemblage with illite as the major constituent. It was again noted, however, that kandite predominated frequently in soils developed on glacial tills derived largely from Carboniferous sandstones (Ann. Rep. 1953-54). The mineralogical composition of clays from a number of Aberdeenshire soils was determined to assist in the elucidation of specific pedological and glaciological problems. A communication dealing with the relationships between clay mineral genesis and soil-formation factors in Scottish soils was presented at an international colloquium in Paris[31].

Numerous soil clays from overseas countries have been examined. Illite was the principal mineral in a large number of soil clays from Malta, whereas Turkish soil clays contained vermiculite-chlorite mixed-layer mineral along with kandite, smectite and illite. Some Australian soil clays were investigated specifically for the quantitative assessment of gibbsite and kandite.

The identification of amorphous clay minerals in soils by differential thermal analysis in conjunction with infrared spectroscopy has developed into a major project. The progress made in this investigation was contained in a paper read before the Clay Minerals Group of the Mineralogical Society in November, 1960.

Minerals examined during the year have included vermiculite, pennine, halloysite, ferric oxides, phosphate rocks, calcites and several gypsum samples. Special consideration has been given to crocidolites and riebeckites, to gibbsite samples of varying quality submitted by the Geological Survey of British Guiana and to samples of saponite submitted by the Nature Conservancy. Dehydroxylation and rehydroxylation studies have been extended to nontronite and to montmorillonite saturated with cadmium, silver and sodium ions. An investigation on the ageing of alumina gels, using a combination of techniques, has been completed.

The examination of organic materials in both oxidizing and inert atmospheres has continued. Protein from animal and vegetable sources received particular attention, the latter at the request of the Arthur D. Little Research Institute.

A Stanton decimilligramme thermobalance with provision for controlled-atmosphere work and suitably modified to give the same heating rate as the differential thermal apparatus is now in operation. This instrument has already provided very valuable results ancillary to those from differential thermal analysis. Currently it is being employed in a study of Iranian soil clays with a high calcium carbonate content.

Chemical Studies. Semi-micro chemical analyses have been restricted mainly to soil clays. Only a few mineral samples have been examined during the year, notably nontronites and pyrophyllite. The value of chemical pretreatments and of accurate chemical analyses as an adjunct in clay mineralogical investigations has been discussed in a paper presented at the conference in Prague[32].

Studies in chemical solubility techniques capable of differentiating between

amorphous and crystalline clay minerals have continued but in considerably greater detail. It appears from a number of tests on pure clay minerals, using either hot or cold 5 per cent sodium carbonate solution as the differentiating agent, that the time of extraction is a critical factor.

SOIL MINERALOGY

Exposure times for X-ray diffraction photographs with the demountable X-ray set have been reduced by about a quarter by substituting beryllium foil for aluminium in the windows. The identification, by X-ray powder diffraction and optical methods, of the clay and fine-sand minerals in soil profiles sampled by the department of Soil Survey has continued in co-operation with the section of Physical Chemistry. Most of the samples originated from Ayrshire and Aberdeenshire and the results have been very similar to those obtained previously for soils from the same areas, with illite as the main mineral of the clay fraction.

Rock Weathering. Two papers on the weathering of basic igneous rocks in south-east Scotland—one on interstratified clay minerals[2] and one on olivine pseudomorphs[3]—have now appeared, and a third more general paper on results from the same investigation has been accepted for publication[33].

Samples of basic and ultrabasic rocks and their associated soil profiles from the island of Rum have been examined. One soil derived from the olivine-rich rock harrisite contained chlorite in the clay fraction, while the fine-sand fraction was almost entirely olivine. Another profile overlying felspar-rich allivalite contained a high percentage of gibbsite in the clay and a sand fraction which was again very rich in olivine; in this instance the olivine was probably transported from neighbouring regions where ultrabasic rocks predominate.

The study of biological weathering, in collaboration with the department of Microbiology, has progressed and a number of pure minerals have been used in preliminary experiments with fungi. A joint paper on a method for studying the breakdown of silicates by soil bacteria[4] has been published.

The addition of a Weissenberg X-ray goniometer to the equipment available will greatly facilitate the investigation of the structure and alteration of single mineral grains.

Other Investigations. A number of specimens have been examined at the request of the Department of Physiological Chemistry of the University of Reading in connection with their investigation of the adsorption of ammonia by vermiculite. The iron oxides present in magnetic separates from pulverized rocks have been identified by X-ray diffraction for the Geology Department of the University of Glasgow. Miscellaneous samples examined at the request of other establishments included extruded specimens for X-ray powder diffraction for the Geology Department of the University of Aberdeen, clay fractions from four soil profiles for the Soil Science Department of the same University, and soil clays submitted by the University of Durham.

A paper on the interactions between clay minerals and phosphates was read at a meeting of the Clay Minerals Group of the Mineralogical Society in

London in November, 1960, and a paper on the weathering of some Scottish basic igneous rocks with reference to soil formation was presented at a joint meeting of the same body with the British Society of Soil Science in April, 1961.

PEAT ECOLOGY

A survey of the major peat deposits on Sheets 87/97 (Peterhead/Fraserburgh), 77 (Aberdeen) and 76 (Inverurie) is nearing completion and acknowledgement is made to the Department of Agriculture and Fisheries for Scotland (Peat Section) for collaboration in the field work. The information obtained is being used to study the stratigraphical relationships of the peat deposits concerned and should, as the survey develops, form a basis for a revised classification of peat deposits in Scotland. In relation to certain proposed schemes for land development, modified survey techniques will be employed, especially in areas where problems of a hydrological nature are present or anticipated.

Ecology. Since January 1959 rainfall, run-off, potential evapo-transpiration, ground water level and conventional meteorological information have been recorded continuously from a 17 acre catchment at Blacklaw Moss, Lanarkshire. Instrumentation is such that the relationship between the hydrological variables can be studied over very short periods. In anticipation of future developments which, in addition to collecting information on the hydrological cycle, will be concerned with the nutrient balance in peatland under different systems of management, a device to sample run-off water at different heads has been successfully installed. Rain water samples are also being collected for chemical analysis. At Coalburn Moss, Lanarkshire, work on the agronomic significance of water in peat has continued along the lines previously reported. Variations in soil temperature are being studied under two contrasting moisture regimes. Both the above experiments are being carried out in collaboration with the Hill Farming Research Organisation.

At Moss Maud, Aberdeenshire, an experiment has been laid down to investigate the factors governing the shallow rooting of species sown on deep peat. The effect of fertilizer placement and rotovation to different depths is being studied. The treatments range from surface seeding to rotovation to 12 inches, and fertilizer has been placed at two depths. The root performance of individual species within the grass/clover sward is being investigated by the radioactive tracer technique previously reported.

In relation to problems of heather management, further samples of soil and vegetation have been taken for analysis from different stands of *Callunetum*. A joint paper on the response of some hill pasture types to lime and phosphate[5] has been published.

Pollen Analysis and Quaternary Research. Pollen diagrams from two sites in the lower Cairngorms have been prepared as part of a study of the forest history of these mountains. This, together with previous work in the Eastern Grampians and on Beinn Eighe, Wester Ross, will help in achieving a better

understanding of the former distribution of forest on upland areas in Scotland.

In collaboration with the department of Soil Survey, peat and other deposits of a more mineral character have been sampled in the Forth valley and in Easter Ross. The pollen information obtained from these samples should add to our knowledge of the quaternary history of the areas concerned.

During the year an invitation was extended to take part in the first scientific investigations in Scotland to be carried out on a Bronze Age hoard unearthed near Strathaven, Lanarkshire. Samples of peat associated with the hoard were submitted by the Glasgow Art Gallery and Museum and by the National Museum of Antiquities of Scotland, Edinburgh, for pollen analysis. A preliminary report has been completed.

A revised method of counting pollen grains, has been devised and a short paper on the rate of peat growth[6] has been published.

Other Investigations. Analysis of peat samples submitted by the Department of Agriculture and Fisheries for Scotland (Peat Section) has continued. In the current year over 700 samples have been received from deposits in Orkney, Roxburghshire and Berwickshire. Physical and chemical determinations have also been carried out on peat and herbage samples from field experimental centres and on material collected in the course of a special survey of peat deposits in north-east Scotland.

Consultative work on many aspects of peat utilization has increased, and the co-ordination of research on fundamental scientific and technical problems associated with the exploitation of peatland in general has continued in collaboration with the Scottish Peat Committee (Moss Survey Group). A report has been prepared reviewing the present position as regards the quality, marketing, and price of horticultural peat and the research in progress. A paper dealing with the origin, properties and horticultural use of peat[34] has been accepted for publication.

The grassland manuring experiments on deep peat at Gardrum Moss near Falkirk, which were established in collaboration with the department of Soil Fertility, are still in progress.

FOREST SOILS

Since 1947 much of the work of the section has been devoted to a study of the physical and chemical changes in the soil resulting from afforestation of sand dunes at Culbin Forest, Morayshire, and deep peat at Inchnacardoch Forest, Inverness-shire. Since 1954, however, fertilizer trials have assumed increasing importance, and with the large amount of peaty land being acquired by the Forestry Commission, the nutrient requirements of trees and particularly the continued growth of older plantations on peat have become of increasing interest.

During the year the approach to investigations into tree nutrition has been critically examined.

Tree Growth on Sand. Sand from some of the most infertile areas at Culbin has been used for greenhouse experiments, and from the results field trials have been laid down. Pot experiments with Corsican pine seedlings suggested

that, as well as there being a deficiency in nitrogen, as was known from earlier work, potassium, phosphorus and sulphur were also deficient; a field demonstration on poor quality Corsican pine, commenced in June, showed in a few weeks colour symptoms suggesting sulphur deficiency in those plots to which no sulphur had been added. An experiment has been started comparing different rates of sulphur in order to test the effects on height and diameter growth. Other investigations are in progress at Culbin to check the effects of boron and copper, different forms, rates, and repeated applications of nitrogenous fertilizers, and potassium-magnesium interactions on young Corsican pine.

Nutrient Content of Peat. The survey of deep peat areas has continued; twelve sites from the Borders to Caithness have been surveyed and the samples taken analysed. The results show that potassium deficiency in trees occurs earliest where the total potassium content of the peat is lowest, and indicate that, in general, responses to phosphate vary inversely with the total phosphorus content of the peat. Sitka spruce has shown good early growth only on sites where there is a total peat nitrogen content of over 2 per cent, and where there is also a relatively high ash content. These results suggest that a chemical survey of newly acquired deep peat areas might eventually be used to estimate suitability for different tree species and the type and amount of fertilizers required.

Results from the experiment at Glentrool, Kirkcudbrightshire, tended to confirm that, as at Wauchope (Ann. Rep. 1958-59), mineralization of nitrogen is more rapid under deep plough ridges.

Advisory Work. Foliage analysis of samples from Forestry Commission fertilizer trials, and from stands showing unsatisfactory growth, has continued. Fertilizer recommendations for Forestry Commission and private nurseries, based on analyses by the department of Soil Fertility, have also continued, and over 350 samples were dealt with during the year.

SOIL ANALYSIS

Analytical determinations have been completed on the soils collected by the department of Soil Survey during the 1959 field season, and the following determinations completed on 1304 samples (213 profiles) collected during the 1960 season: exchangeables bases, readily soluble phosphorus, total carbon, and total nitrogen. Hydrogen ion concentration and loss on ignition determinations have been carried out on about three-quarters of the 1960 samples and mechanical analyses and exchangeable hydrogen determinations on approximately two-thirds. In addition, standard analyses have been nearly completed on 87 samples of the 1961 soils and 51 samples in connection with studies on forest soils.

Clay, silt and sand samples separated from 84 soils from various parts of Scotland have been analysed for total silica, iron and aluminium.

About 100 samples of surface soil have been analysed for the Hill Farming Research Organisation and for the Nature Conservancy, while total analyses of peat and peat ash samples were completed for the North of Scotland

Hydro-Electric Board. Miscellaneous analyses of 80 samples were carried out on behalf of other departments of the Institute and the Department of Soil Science, University of Aberdeen.

Studies on the ability of the components of aqueous extracts of pine needles to complex with sesquioxides have continued in collaboration with the department of Soil Survey.

SOIL SURVEY

In mid January the department moved into new premises which consist of surveyors' rooms, cartographic and drawing office, map store, monolith preparation room, monolith room, botanical laboratory and dark room. The monolith room will eventually house a large collection of monoliths representative of the main soil series of Scotland; it will also be used for demonstrations and discussions.

Soil mapping on a scale of 2·5 inches to 1 mile has continued in the six areas under survey. A total of 520 square miles has been completed during the season. This comprises 90 square miles on Sheet 84 (Nairn); 65 on Sheets 94 (Cromarty) and 93 (Alness); 90 on Sheets 33 (Haddington), 34 (Eyemouth) and 41 (North Berwick); 100 on Sheets 7 (Girvan) and 8 (Carrick); 90 on Sheets 48 (Perth) and 49 (Arbroath); and 85 on Sheet 39 (Stirling).

Mapping has now been completed in the Haddington, Eyemouth and North Berwick area. Some 34 square miles of revision of the northern parts of Sheet 66 (Banchory) have been undertaken. One hundred and ninety-five soil profiles have been collected from all areas.

A general account of the semi-natural vegetation communities and their relationship with major soil groups has been prepared for inclusion in due course in the Memoir of Sheet 14 (Ayr). The vegetation of Sheets 33 (Haddington) and 34 (Eyemouth) has been recorded. The long-term permanent vegetation quadrats on Scare Hill Forest Reserve, Tillyfoure, Aberdeenshire, previously studied in 1949, 1952 and 1957, have been remapped with the object of recording changes in vegetation, growth increments in trees and changes in soil morphology as a result of planting. The intensive soil-vegetation survey of a granite hill—Mount Shade, Kincardineshire—has continued. The soil and vegetation of randomized plots has been recorded for the purpose of comparison with the heath vegetation and soils on a basic rock hill in Glenbuchat, Aberdeenshire, where similar records have been made.

A paper on the principles of soil classification[28] has been accepted for publication.

Ad hoc investigations have included: (a) Preparation of a report and two meetings attended with officials from the Department of Agriculture and Fisheries for Scotland on the soil restoration at Oxwell Mains, Dunbar, the proposed site for open cast mining of limestone by the Associated Portland Cement Manufacturers Ltd.; (b) Preparation of a report for the East Lothian Planning Office on the soils and soil restoration of East Saltoun limestone quarry; (c) Visits to transmission lines of the South of Scotland Electricity Board in central Scotland to try to establish a relationship between soil type and the degree of corrosion in the tower stubs. The incidence is slight on freely drained sites, but on imperfectly drained, poorly drained and very poorly drained sites there is always the possibility of intense corrosion. The suggestion of fitting magnesium anodes to the towers is to be examined by

the Board; (d) Collaboration with the Colleges of Agriculture and departments of the Macaulay Institute in siting fertility trials and in obtaining representative soil and plant material for detailed studies on clays, trace elements and organic matter. Two of the Colleges have instituted trials on the effect of the disruption of the pedological indurated layer: a paper on the origin of this horizon[29] has been submitted for publication.

Assistance has been given to various organizations: to the Forestry Commission in characterizing soils; to the University College of North Wales in a talk and in leading an excursion in Scotland for students; to the Geography departments of various Universities and the Waid Academy, Anstruther, in giving soil information.

Various archaeological excavations were visited and soil samples obtained. An appendix on the soils of the Dalnaglar Hut Circle, Glen Shee, Perthshire, has been prepared for inclusion in a paper by the Archaeological Department of the University of Edinburgh.

The survey of Sheet 57 (Forfar) has now been completed and the map submitted to the Ordnance Survey for printing. In the mapping on Sheets 57 (Forfar), 66/67 (Banchory/Stonehaven), 48/49 (Perth/Arbroath), and 39 (Stirling) of soils in Strathmore derived from Old Red Sandstone sediments, it was found necessary, as a more comprehensive knowledge of the soils was obtained, to make a reassessment of certain of the originally distinguished soil series. This has been completed for Sheet 57 and it is therefore now possible to summarize briefly the geology, soils, and agriculture of this sheet.

Sheet 57 (Forfar)

The sheet covers an area of approximately 357 square miles, situated in the counties of Kincardineshire and Angus. The Highland Boundary Fault separates the region into two distinct parts. On the north-west side of the Fault, between Edzell and Glenquiech lie some 42 square miles of the Grampian Highlands—heather-covered mountainous country ranging up to nearly 2,500 feet—whilst to the south-east lies the gently rolling, intensively cultivated farmland which forms part of Strathmore. Included in the sheet are the districts around the towns of Montrose, Arbroath, Brechin and Forfar. Some of the larger villages, which are market centres, are Edzell, Friockheim, Letham, St. Cyrus, Johnshaven and Inverkeilor.

The drainage pattern is dominated by three main systems, the North Esk, the South Esk, and the Forfar-Lunan channel. Both the North and South Esk rivers rise in the Grampians and drain eastwards through deeply cut valleys to the lowlands and into the North Sea. The Forfar-Lunan channel drains both westwards and eastwards: westwards from Forfar Loch *via* the Dean Water and River Isla into the Tay, and eastwards from Balgavies Loch into the Lunan Water.

The landscape pattern is basically determined by the solid geology, though modified in detail by the effects of glaciation. North of the Fault the Grampians consist of smooth, steep-sided hills and ridges underlain by acid, flaggy

quartz-schists, with mica-schists and phyllites of the Highland Schist Formation. The only igneous rocks in this region are acid felsite dykes, associated with the main mass of the Kincardineshire granite to the north, and very occasional dolerite dykes. The Fault zone itself is occupied by the Highland Border Series, a narrow band of highly-cleaved lavas and plutonic rocks considered to be of Cambro-Ordovician age. South of the Fault zone almost the entire remaining part of the sheet is underlain by sediments and lavas of Lower Old Red Sandstone age and forms part of the Strathmore syncline. The succession is made up of dull red coloured sandstones, conglomerates, flagstones and occasional limestones with bright red marls and mudstones in the upper part. The latter are particularly well developed in the neighbourhood of Edzell and Laurencekirk, the region known as the Howe o' the Mearns. The lavas, which are andesites and basalts, outcrop particularly in the coastal side of the area and are extensive south of Montrose. Minor patches of Upper Old Red Sandstone strata occur just north of Arbroath, but do not appreciably affect the soil.

The terrain underlain by the Old Red Sandstone presents a vista of a broad rolling plain with long low parallel ridges rising from it. The ridges are formed by the glacially smoothed edges of the underlying sandstone strata. The Garvock Hills stand out in the north-east as parallel ridges rising to 400-600 feet, running in a north-east to south-westerly direction and formed from the harder sandstone, conglomerates and lavas. The Aberlemno Hills and Rossie Moor are hill ridges which protrude from the central part of the plain, Rossie Moor forming the highest part of a prominent broad smooth area of rising ground, underlain by lava, separating the Montrose Basin and Lunan Bay. In the extreme south-west corner of the sheet Hayston Hill, rising to over 1,000 feet, forms the eastern end of the Sidlaws. The topography of the southern part of the sheet, south of Forfar and extending to Arbroath, is more hilly, with the hills falling both in altitude and frequency from west to east.

The regional relief, determined by the underlying solid formations, has been modified by glaciation. It is considered that during the Pleistocene Period north-east Scotland experienced three cycles of glaciation. The first left little evidence of its passage in the area. The second was the most intensive, and at its peak the British and Scandinavian ice sheets were locked edge to edge roughly along the present line of the coast. Ice from the Central Highlands moved down into Strathmore and was deflected in a north-easterly direction by the Sidlaw Hills. It was in this second and maximum period of glaciation that the bulk of the glacial drift which forms the soil parent material was deposited The final glacial period was of relatively low intensity with Piedmont glaciers from the Grampians thrusting out as discontinuous tongues into Strathmore. Extensive fans of morainic gravel and alluvial deposits were laid down at the mouth of the glens, as at Edzell, and the meltwaters caused extensive water-working of the glacial tills laid down in the second or maximum ice period. Throughout Strathmore, where there are

large areas of gently undulating to gently rolling topography, the till within soil profile depth shows evidence of water sorting in the upper horizons and is coarser in texture than the till below. The depth of the modified layer is variable; it may be absent, but generally extends to 15 or 24 inches. Below this layer there is usually a compact clay loam or sandy clay loam till.

At the Highland edge the moorland limit is marked by the 40 inch isohyet, and there is a sharp increase in rainfall to more than 55 inches in the Grampians. The main part of the arable region of Strathmore receives 30 to 35 inches, with rather less than this in a narrow belt along the coast. The average daily amounts of sunshine in Angus throughout the year, 3·6 to 3·85 hours, are higher than those in western parts of Scotland. Maximum sunshine occurs in June, when the mean daily duration exceeds 6·5 hours. July and August are two of the rainiest months, January and February are the coldest months and July is the warmest, August being slightly cooler.

The main effect of climate and parent material on soil formation has been to produce moderately leached soils in lowland Angus on the Old Red Sandstone parent materials and strongly leached soils in the Grampians on the Highland Schists. Iron podzols, peaty podzols and hill peat predominate in the highland area, while brown forest soils, brown forest soils with gleyed B and C horizons and, to a lesser extent, iron podzols predominate in the lowland. The genetic soil groups in the lowland arable region are less easily defined, owing to cultivation. Podzols are encountered in areas of semi-natural vegetation remaining in lowland Angus, but are often on less favourable parent materials and have in consequence remained uncultivated. It is considered that the podzolizing influence is of relatively recent origin and the soils have degraded from brown forest soils. Where deep till sections have been encountered it has frequently been found that below a depth of about 7 feet the till is calcareous; this is not secondary carbonate because in a deep gully the carbonate extended to more than 30 feet. Further evidence of the carbonate-rich parent material is that many of the Angus lochs contain layers of soft white calcareous marl. These have been extensively exploited for agricultural use in the past. Such deposits represent the gradual accumulation of free calcium carbonate leached from the till in their surrounding catchment basins. In a boring made at the east end of Restenneth Moss three distinct layers of marl were recorded. Pollen analysis showed that the lowest bed was formed during the early Boreal period, the middle bed during the Atlantic period and the uppermost layer during the Sub-Atlantic period, the most recent period of intensified leaching.

There is a singular absence of gley soils in the lowland region, due no doubt to the porous nature of the underlying sediments. Soils with imperfect rather than free or poor drainage predominate. These are soils which approach the ideal agricultural soil. They require only occasional field drains, and neither burn in a dry season nor become waterlogged in a wet one. The high reputation of the agriculture of the region is to some considerable extent due to the inherent quality of these soils.

The various soils of the region have been grouped into 11 associations:

Association	*Parent Material*
Laurencekirk:	Till derived from Lower Old Red Sandstone sediments, mainly marl and fine grained sandstone. The above till with water-modified surface.
Stonehaven:	Till derived from Lower Old Red Sandstone sediments, mainly conglomerate with some andesitic lava.
Mountboy:	Till derived from Lower Old Red Sandstone andesitic and basaltic lava and sediments.
Balrownie:	Till derived from Lower Old Red Sandstone sediments, mainly sandstone. Water-sorted material, generally <2 feet, overlying the till.
Forfar:	Water-sorted material, generally >2 feet, overlying till derived from Lower Old Red Sandstone sediments.
Strathfinella:	Till derived from arenaceous Lower Old Red Sandstone, acid igneous and acid metamorphic rocks.
Strichen:	Till derived from quartz-mica-schists.
Auchinblae:	Red fluvio-glacial sand and gravel.
Boyndie:	Fluvio-glacial sand.
Corby:	Water-sorted and morainic gravel.
Pow:	Silty estuarine alluvium.

The above associations, which contain 37 soil series, together with hill peat, basin peat, alluvium, links, dune sand, raised beach shelly gravel, saltings and skeletal soils, form the units distinguished on the soil map. Some of the series are of small extent and are of significance only in so far as they represent major soil groups on parent materials differing from the more commonly occurring series.

A peaty podzol with iron pan, which is represented by the Gaerlie series of the Strichen Association, is the most widespread soil in the highland area. It occurs under wet heath, with *Calluna vulgaris*, *Erica tetralix*, *Trichophorum caespitosum* and *Sphagnum* spp. on a stony shallow till. It has a well developed layer of raw humus, overlying a 4 to 6 inch A_2 horizon, above a thin continuous iron pan. Beneath the pan drainage is free, but above it gleying occurs in the lower part of the A_2 horizon. On flat plateaux, hill peat occurs; this accumulates by thickening of the organic horizon of a peaty podzol soil. Beneath the hill peat a waterlogged A_2g horizon overlies an iron pan and beneath the pan the sub-soil is yellow-brown in colour and freely drained. Skeletal soils and bare rock occur on the summits of the hills.

Iron podzols, of which 9 series have been distinguished on different parent

materials, are an extensively occurring genetic soil group. These are soils which are freely drained. In the semi-natural state they have a raw humus layer of about 1 to 3 inches, an A_2 horizon of some $\frac{1}{2}$ to 2 inches, and a friable B_2 of some shade of yellow or reddish brown, which overlies a strongly indurated B_3 horizon. They support *Callunetum*, and have a surface pH value of between 4 and 5·5. Whilst being strongly leached soils and generally less than 20 per cent saturated, they are less leached than the peaty podzols. They occur on moderate slopes and tend to occupy hilly areas in lowland Angus. Considerable areas have formerly carried birch and Scots pine which have since been cut over and are now utilized for sheep grazing. Where cultivated, the soils tend to have a loam to sandy loam surface horizon and their agricultural quality, excluding management, depends on the depth to the indurated horizon. The Aldbar series occupies 40 square miles of the Balrownie Association and is widely distributed. Developed on a till, generally less than 4 feet thick, derived from sandstones and flags, the soils have a clay content varying between 10 and 20 per cent. The pH of the surface of the arable soils is now above 6, but the sub-surface value may be only 5. Exchangeable Ca usually falls to low values in the B_2 and B_3 horizons. Total phosphate is highest in the S horizon, with a value around 0·25 per cent, and is generally found to be less than 0·1 per cent at some part of the profile. The Vinny series of the Forfar Association, developed on at least 2 feet of water-sorted material overlying a clay loam till at depth, is lower in clay and nutrient content than the Aldbar series but resembles it in the texture of the S horizon. The Shields series of the Stonehaven Association, developed on an Old Red Sandstone conglomerate till, has a clay content of between 10 and 20 per cent, but it is stony to an extent sufficient to be a handicap to cultivation. The Strathfinella series, developed on till derived from arenaceous Old Red Sandstone rocks, together with quartzites, quartz-schist and granite, is a moderately coarse-textured soil occurring on hilly topography, and extensive areas are in permanent grazing. The Auchinblae series on red coloured sand and gravel, the Boyndie series on fluvioglacial sand and the Corby series on gravel are all coarse-textured soils, inherently low in nutrients and subject to drought.

Brown forest soils with free drainage are characterized by a mull moder surface horizon with crumb structure which merges into a B_2 horizon. The latter is reddish in colour in soils derived from Old Red Sandstone sediments and brownish in soils from acid igneous and metamorphic rocks. In this area the indurated horizon is usually weakly developed. Representative of this group is the Garvock series of the Mountboy Association, derived from andesitic lava. It is commonly over 50 per cent base saturated and C horizons commonly have pH values between 6 and 7. Small areas of this genetic soil group have been distinguished in the Laurencekirk and Strichen Associations.

Brown forest soils with gleyed B and C horizons, imperfectly drained, occur on gentle slopes on moderately fine-textured parent materials. Seven series have been mapped, of which the Laurencekirk, Stonehaven, Mountboy and Balrownie are the most extensive in their respective associations. The

greater part of these areas is cultivated and considered to be agriculturally very good. With clay contents varying between 10 and 30 per cent, the soils generally have loam S horizons with a coarse crumb to sub-angular blocky structure and sandy clay loam B(g) horizons with coarse blocky to prismatic structure. Some ochreous and grey mottling is present in the B(g) and C horizons. Induration is only weakly developed. The Balrownie series, developed on water modified Old Red Sandstone sandy clay loam till, frequently has a sandy loam B horizon. This series covers approximately 70 square miles and is the dominant soil type in the arable region. It requires little tile drainage and has been long farmed. The pH of the C horizon often approaches or exceeds 7. Exchangeable Ca is normally high in the S, falling to a minimal value in the B(g) and rising to a moderately high value in the C horizon. Exchangeable Mg is highest in the C where the value is approximately one-third that of Ca. The percentage saturation of arable soils is usually high, 50 to 100 per cent, although in semi-natural woodland this is true only of the C horizon. Total phosphate is, however, comparatively low in these soils, being less than 0·2 per cent. This tends to be rather lower than in some of the freely drained series. There is a tendency for high levels of extractable phosphate to occur in the Mountboy Association.

The Laurencekirk series, developed on till derived from bright red marl and fine grained sandstones, is sufficiently bright coloured to obscure the ochreous mottling present. Manganese staining in the lower B(g) horizon is often conspicuous and, together with the prismatic structure, is indicative of the imperfection of the drainage. The Luther series which is a water-sorted variant of the Laurencekirk series bears comparison with the Balrownie.

Of the iron podzol group of soils with imperfect drainage, the only series of significant extent is the Forfar series. This occurs in footslope positions and flat terraces bordering the well-defined drainage channels and is developed on water-sorted material, of a depth usually greater than 2 feet, overlying sandy clay loam till. The surface soil is a loam which passes into sandy loam (clay content around 10 per cent) overlying the till. Under good management it forms very good arable land and is easily cultivated.

Non-calcareous gleys in this area are found only in small patches, while peaty gleys are virtually non-existent. It is interesting to compare this area of eastern Scotland with Sheets 22 (Kilmarnock), already published, and Sheet 14 (Ayr), reported on in the previous Annual Report, where 18 series of non-calcareous gleys and 14 series of peaty gleys formed the largest category of soils mapped. The Pow series, situated on the west side of Montrose Basin and developed on silty estuarine alluvium, is now arable land reclaimed from reed swamp. The silt content greatly exceeds the clay and the surface texture is silty clay with silt loam, *i.e.*, over 50 per cent ·002 to ·05 m.m. silt, in the lower horizons. The soil is up to 90 per cent base saturated but has a surprisingly low pH value of 3·2 at a depth of 36 inches. The poorly drained Lour series of the Balrownie Association exhibits the well established trends for gley soils. It has a higher clay content than the free and imperfectly drained counterparts and a higher percentage base saturation, being 100 per

cent saturated with a pH of 7 to 8 at a depth of 12 inches. Accompanying the high pH values is an increase in the acetic extractable P_2O_5, 20-50 mg./100 g. as compared with less than 10 mg./100 g. in the S horizon, while exchangeable Mg increases in depth to a value amounting to 50 per cent that of Ca.

There is a strong similarity in the mineralogy of the clay fraction of all soil associations on Old Red Sandstone parent materials. The kaolin content varies from about 10 to 30 per cent, being low in Mountboy and Forfar and high in the Laurencekirk soils. Illite is always the major component, its content varying from 35 to 60 per cent. Vermiculite and chlorite occur erratically and seldom exceed 10 per cent. Montmorillonite is generally absent in the surface layers and throughout the well drained profile, but may reach 20 per cent in the lower layers of the poorly drained soils of the Stonehaven and Balrownie Associations.

In the fine sand the light fractions (specific gravity $< 2{\cdot}89$) usually comprise 80 to 90 per cent of the total and are mainly composed of quartz and felspars. In the heavy fractions iron oxides are often the commonest constituent; the remainder is variable in mineralogy, depending on the heavy minerals in the parent rock, but biotite, hornblende, garnet and augite are usually common.

Lowland Angus is an intensively farmed arable region. The county was formerly one of large estates, but with the exception of three fairly large estates these are now broken up and over 50 per cent of the farms are owner occupied. A considerable amount of multiple farming is to be found. The size of holding varies from one to over 600 acres, the average being from 100-200 acres arable. The district is generally considered to be one of relatively large farms.

The main agricultural policy is the production of fat cattle, and there is a big demand for store cattle. Dairying is not important, but there are a number of Ayrshire, Friesian and Dairy Shorthorn herds. The highland glens carry flocks of Black Face sheep which are known for their size and hardiness. On the low ground there are several well known pedigreed flocks of Border Leicester and Suffolk sheep.

The traditional rotation followed is oats, potatoes, wheat, turnips, barley, hay, and pasture, but many variations are now found. Because of the increased use of harvesters, the acreage of cereal crops, particularly barley has increased in recent years. A few farms in the 400 acre category grow no other cereal; yields are 30-36 cwts. per acre. Wheat is grown extensively, particularly along the eastern part of the area; yields are about 26-30 cwts., although 56-60 cwts. have been recorded. With intensive arable farming grassland is put down for two years and is used for hay the first year and grazed the second. Potatoes for seed are grown extensively. Sugar beet, grown on contract, has gained in popularity so that acreages have now to be limited by the Sugar Corporation; yields are slightly over 10 tons per acre. Swedish turnips are being grown in decreasing quantities, being replaced by silage. Peas for canning and raspberries occupy considerable acreages. Canning factories are located in Montrose, Arbroath and Forfar.

The area has a good network of roads and is well served by rural transport.

Electricity is available in all parts, including the glens. The relatively large size of farm has in many ways lent itself to modern mechanization, and only the harvesting of the soft fruit and potato crops requires a large force of casual labour.

The general level of fertility over the area as a whole is high, and wide use is made of soil analysis and the agricultural advisory services. The proportion of fields requiring lime is small; most have now been limed to a satisfactory level. The phosphate level in the soils is now generally high, but potash is considered to be less satisfactory.

SPECTROCHEMISTRY

During the year the main efforts of the department have been directed towards the reorganization made necessary by removal to new laboratories. This has been particularly the case in the trace element work, where the opportunity has been taken to introduce slight modifications in techniques and equipment, as full restandardization, requiring several months' work, was necessary in any case.

Visiting workers who have spent extended periods in the department include Mr M. M. Guha, from the Rubber Research Institute of Malaya, who has now submitted his thesis to the University of Aberdeen on "*The Trace Element Uptake of Deciduous Trees*," Miss Beate Berner of the Statens Rastofflaboratorium, Trondheim, Norway, and Mr R. A. Chen, Agricultural Chemistry Division, Ministry of Agriculture and Lands, Jamaica. Shorter visits to learn techniques were paid by workers from Malaya, Yugoslavia, and South Africa.

Members of the staff attended the Ninth International Spectroscopic Colloquium in Lyon, France, which was attended by over 600 spectroscopists, and the Fifth European Congress on Molecular Spectroscopy in Amsterdam, Holland, which was equally well attended. These international gatherings provide an excellent opportunity for private discussions of problems of mutual interest by workers from different countries, and considerable benefit to the work of the Institute is derived from attendance at such meetings.

Trace Elements in Soils, Plants and Biological Materials

Soils and Soil Parent Materials. An account[7] of the trace element distribution in some typical Scottish soil profiles has now been published. It appears that, in the rather young soils of Scotland, the most important factor governing the total content of trace elements is the geological nature of the parent material. Pedological factors appear to affect total contents only in very much more mature soils. They are important in determining the amounts of extractable trace elements, and here the effect of soil drainage on the mobilization of elements such as cobalt, nickel, copper, manganese, molybdenum, zinc and lead is particularly important. Work on this aspect is continuing, as is the study of trace elements in further typical profiles from the areas presently being studied by the soil surveyors.

Soil Status and Plant Uptake. The fundamental difficulty in using leaf analysis as a measure of soil status is the variation in leaf composition, both with position on the plant and with time of sampling. These factors apply in all types of plant from grasses to trees. For instance, it has been found that the zinc content of cocksfoot leaves may vary up to 10-fold depending on nodal position, being highest in the upper leaves. This effect can result in very significant differences in whole plant samples cut at slightly different heights above the ground. A comprehensive study by a visiting research

worker of the contents of 24 elements in the leaves of three species of deciduous trees at different tree heights throughout the growing season has just been completed. This study was extended in one species (beech) to different soil associations in order to correlate leaf content with soil content. Quite distinct trends for different groups of elements have been observed. In general, in so far as seasonal and positional changes are concerned, the behaviour of the essential trace elements differs from that of the trace elements currently regarded as non-essential and both differ from that of the major nutrients. This work should prove useful to other workers, as it presents information for many elements not previously studied comprehensively in tree-crops and should assist in the study of their nutrition.

Collaboration with other departments, particularly Soil Fertility and Plant Physiology, has continued. In addition to the examination of soil and plant samples for diagnostic purposes, further investigations into soil-plant relationships in trace element field experiments have been made. These include the study of the effects of lime and various fertilizers on trace element uptake of different species, and the long-term study of the effect of cobalt and other trace element soil treatments on the uptake by pasture herbage species.

Spectrochemical Methods of Analysis

The total number of samples examined during the year for trace element content by spectrochemical methods has fallen by about 300 samples (10 per cent) compared with last year, as a result of the interruption caused by removal. There has been an increased requirement for the determination of magnesium by direct photometry and despite the break there has been an increase of 1,100 samples (12 per cent) in the number examined during the year. The demand for magnesium determinations from other departments is currently around 40 per day.

Arc Emission. Minor modifications in the arc emission set-up include the replacement of the manual 20A D.C. main switch by a double pole mercury relay operated by the first step of a tapped switch, subsequent steps of which operate the relays of the current-controlling arc resistance. The step giving a current about 6A also brings into operation a clock which indicates duration of arcing, and which returns to zero at the conclusion of the burn. Thus, all the operations involved in starting an arc are performed by one rotary switch. The positioning of the electrode prior to arcing has been simplified by the use of a mirror bearing a horizontal line at the proper arc height placed behind the arc when viewed from the operator's position. Coincidence of the electrode tip and its image on the line indicates that its height is correct.

In the technique used for the determination of copper by direct ashing of plant ash admixed with potassium sulphate and carbon powder, the arc length has been reduced from 10 mm. to 6 mm. with no loss of sensitivity or reproducibility, but with much less tendency for the arc to creep up the anode and strike to the electrode holder.

Flame Emission. Demands for determinations of potassium, sodium and calcium by flame photometry have been on a scale similar to previous years.

No changes in the technique have been introduced, although, as reported below, the original flame photometer is now being rebuilt.

Direct Photometry. The Hilger Medium Direct Reader is in regular use for copper in EDTA soil extracts by the porous cup solution spark technique, as well as for such elements as zinc, iron, manganese and aluminium in various types of samples by the same technique. It is interesting to note that, despite statements to the contrary in the literature, experience here has been that the lower limit of determination for several elements is at least as good by direct reader as by photographic spectrographic techniques using the same source and the same spectrographic optics. Thus, for instance, contents of 0·1 p.p.m. copper in solution are readily determined and amounts as low as 0·02 p.p.m. are appreciably above the blank reading.

The rotating disk method for the examination of plant ash in a rotating pressed disk in admixture with cellulose and graphite has been described in two publications [8, 35]. This technique has been used for the examination of several hundred leaf samples for aluminium, silicon, boron and phosphorus. Results are also available by this technique for zinc, iron, manganese and copper. Acceptable agreement has generally been obtained with results by other methods.

Laboratory Facilities. Within the new department an attempt has been made to overcome many of the difficulties encountered in trace element analyses and the operation of spectrochemical equipment in the old building. These involved contamination and corrosion problems[9] and the maintenance of suitable operating conditions, particularly in respect of temperature and humidity.

Provision has been made for soil drying, sieving and weighing out on Floor 1 and for plant drying, milling and weighing out on Floor 2, thereby separating them from the analytical work and from each other. Individual dust control units (Dallow Lambert Drytex DT25) have been installed where required. For soil sieving and quartering, use has been made of the cleaned air to protect the operator by directing a stream of air at an angle over the work bench from the front. Lathes and cutters for the preparation of carbon electrodes are also installed on Floor 1. In this instance, the dust problem is effectively dealt with by a Dallow Lambert Unimaster, Type G1-102, positioned in an adjoining sound-baffled room, together with other services, including the air-compressors for flame photometry.

The chemical laboratories and instrument rooms are on Floor 3. In an air-conditioned wing are rooms for emission and absorption work, temperature controlled at 68°F. In the rooms for infrared and ultraviolet absorption, humidity is controlled at around 40 per cent R.H. to protect alkali halide prisms. In the other rooms it is about 50 per cent R.H. The operation of the air conditioning equipment is not yet completely reliable.

In the emission section, two Hilger Large Quartz spectrographs, the Hilger Medium Direct Reader and the small direct reader for magnesium have been transferred and recalibrated. Still awaiting installation are Hilger Large and Medium Quartz spectrographs transferred from East Malling by the

Agricultural Research Council and a third Hilger Spectral Line Microphotometer which will be required to measure the plates taken on these instruments. The rectifiers and resistances for the supply and control of direct current for arc work have been fitted in a cubicle adjoining the spectrograph alcoves, with facilities for complete interchangeability of supply. This arrangement also ensures that the heat dissipation from the resistance does not interfere with the temperature control. The modified resistances, with solenoid operated mercury switches, described in the 1958-59 report, are operating very satisfactorily. Dark-room facilities are provided adjoining the spectrographs.

Flame photometry is carried out in a room adjacent to the main laboratories. At present the three channel research flame photometer is being used for routine analytical work, as the opportunity is being taken to rebuild the original instrument which was built as an experimental prototype in 1949 and has been in continuous operation since then. It was possible to avoid any interruption of analyses of K, Na and Ca for other departments, although a break of two weeks was required to transfer and recalibrate the magnesium direct reader.

Some details of the precautions being taken against contamination in the chemical laboratories were given in the 1959-60 report. These appear to have been reasonably effective, as substantial reduction of the blank level in the determination of EDTA-extractable copper in soils, to around one-third of its former value, has been achieved. Blank values, involving all reagents, filtrations and extraction processes are now around 0·02-0·04 p.p.m. Cu, while the lowest soil contents are about 0·3-0·4 p.p.m. Cu. The polypropylene water-baths, aluminium alloy (5 per cent Mg) hot plates and PVC-lined fume cupboards, fitted with false floors to permit flush mounting of baths and hot plates, are all operating satisfactorily. Throughout the building provision has been made for roof-mounted controllable-speed fans for individual fume cupboards, giving a maximum extraction rate of 5 air changes per minute.

In the laboratory in which preparations for absorption work are carried out, the precautions required are sometimes different to those for trace-element work. For instance, distilled water from a glass still is stored in glass rather than polythene, in order to eliminate the possibility of absorption bands from the plastic material confusing the interpretation of ultraviolet spectra.

Balance rooms are located conveniently between the chemical laboratories, while rooms for shakers, ovens and muffles, electrode filling and evaluation of microphotometer readings of spectrograms are situated opposite the laboratories.

Several small rooms are available as laboratory offices for the members of staff, as the nature of spectrochemical work, involving movement from one type of process to another, makes writing positions in the laboratories impracticable. In addition, a small workshop for electronic servicing and development

of specialized equipment and a departmental office for the filing of records and abstracts have been provided. The total floor area within the department is some 8000 square feet, of which laboratories account for almost half and instrument rooms one-quarter, the remainder being soil and plant preparation rooms, service rooms and offices. The staff of the department is now 23, and there are generally also several visiting workers and research students.

Absorption Spectrometry of Soil Constituents

The study of the infrared spectra of soil clays presents a range of problems which are being actively investigated. To provide standard spectra, a number of pure well-characterized clays have been studied in detail. This work has shown that the infrared spectra of clays are a function of both composition and structure. Thus, in the expanding clay minerals derived by isomorphous substitution in the pyrophyllite structure, a clear distinction can be made between those in which aluminium takes the place of silicon (beidellite) and those in which magnesium takes the place of aluminium (montmorillonites). Substitution of iron for aluminium also gives rise to distinctive features in the infrared spectrum, which allow an estimate of the degree of substitution to be made.

The problem of the characterization of amorphous clays is being pursued in collaboration with the section of Physical Chemistry. Clays in which amorphous material predominates are readily characterized as such by their infrared spectra, but difficulties are encountered when amorphous clays are admixed with crystalline material. Preliminary work suggests that these may be best distinguished by their water-holding capacity and by their hydroxyl groups. A detailed study is therefore being made of the hydroxyl absorption which arises from adsorbed and constitutional water in clays, and of the variation in this absorption with variation in the exchangeable ions present. The Grubb-Parsons S4 infrared spectrometer has been modified to accommodate a grating which can be used instead of the prism in the 3 μ region to achieve the high resolution necessary for investigating hydroxyl group absorption in this region. This increased resolution has revealed distinctive absorption bands in clays which were not evident with the lower resolution provided by a sodium chloride prism.

The infrared examination of soil clays requires the removal of organic matter, which gives absorption that obscures points of interest in the spectra of the clays. Treatment with hydrogen peroxide has been found to leave a residue of complex oxalates, most of which are sufficiently soluble to permit their extraction with water. The presence of exchangeable calcium in the clays leads to the formation of insoluble calcium oxalate, but this can be avoided by first saturating the clay with ammonium ions. A report of this work, which has been carried out in collaboration with the section of Physical Chemistry, was presented at the November 1960 meeting of the Clay Minerals Group of the Mineralogical Society.

Investigations on the metabolism of lignin in wood and of lignin model compounds by *Polystictus versicolor* have been pursued in conjunction with

the department of Microbiology, and a joint paper has been published[10]. Further work on the pressed disk technique has been necessary to establish the nature of the anomalous hydroxyl absorption found in disks containing aromatic compounds. It has been established that the hydroxyl absorption arises from adsorbed water, which, although always present on finely ground alkali halides, is greatly increased in amount when certain aromatic compounds are present during the grinding process. The increase in adsorbed water is correlated with adsorption of the aromatic compounds on the alkali halides. The results of this work were reported at the Fifth European Congress of Molecular Spectroscopy, in Amsterdam, in June 1961.

BIOCHEMISTRY

The department completed the occupation of its new laboratories in June, and has already felt the benefits of more space and improved facilities. The latter include a small laboratory in which the temperature is maintained at 5°C, special rooms for chromatographic and physical apparatus, and a laboratory for work with large quantities of raw material. The increased space makes it possible to use equipment more profitably, and to provide reasonable accommodation for visiting research workers. Mr Andrew Dowgiallo from the Nencki Biological Institute in Warsaw, who spent two months with us at the beginning of the year, was the last visitor to endure the old crowded conditions.

Organic Acids in Leaves. One mechanism by which sugars are oxidized to provide energy for vital processes in plants (as in many other organisms) is the citric acid cycle. Citric acid, which contains six carbon atoms, is formed by the combination of a four-carbon acid with a two carbon degradation product of the sugar; it is then converted by stages into malic acid (four carbon atoms), two molecules of carbon dioxide being formed as by-products. The removal of two hydrogen atoms from malic acid brings the process back to its starting point, and the cycle is repeated.

Citric and malic acids (and two other acids of the cycle: aconitic and fumaric) were first isolated from, and named after, plants which accumulate them. The presence of these acids in plant tissues is thus linked closely to the major metabolic pathways.

Following the discovery that iron-deficient plants show a subnormal activity of the enzyme aconitase[11, 12], a study has been made, in collaboration with the departments of Plant Physiology and Spectrochemistry, of the accumulation of malic and citric acids by mustard leaves under various conditions. It was thought possible that iron-deficiency, by interfering with aconitase, which assists in the conversion of citric acid to malic acid, might affect the relative amounts of these acids in the leaves. Statistical analysis showed that iron-deficient leaves contained always less malic acid and sometimes more citric acid than normal leaves. Considerable variations in the calcium, potassium and phosphate content of the nutrient medium had no effect upon the citric acid content, but high potassium with low calcium depressed the malic acid by about 25 per cent.

Further study showed that during growth and maturity the malic acid and calcium contents of the leaf increased considerably, and in approximate equivalence: the potassium and citric acid contents also corresponded closely, but changed little. However, as soon as the leaves began to turn yellow the malic acid content fell sharply and the citric acid rose until their relative concentrations were reversed. During this period of senescence there were no consistent changes in the calcium and potassium contents. Experi-

ments are being continued to try to discover whether there is a direct connection between the metabolism of malic acid and calcium, so that control of the accumulation of one might control the uptake of the other.

Solubilizing of Minerals. Further quantitative studies in collaboration with the departments of Microbiology, Pedology and Spectrochemistry have confirmed the pronounced mineral-solubilizing action of rhizosphere micro-organisms that produce 2-ketogluconic acid[4] (*see* Annual Report 1958-59). One such organism, growing in nutrient medium containing 200 mg. glucose and 25-50 mg. of insoluble mineral, liberated as much as 40 per cent of the calcium of phosphates and silicates, including hydroxyapatite; the presence of fluoride depressed this figure to about half. The liberation of phosphate was in all cases roughly equivalent to the cation (metal) released. The chelating action of 2-ketogluconic acid, on which the solubilizing action depends, is exerted mainly upon divalent metals (calcium, magnesium, manganese, etc.), and it is much less effective in removing other cations and hence in releasing the phosphate combined with them; for example, only 2 per cent of the phosphate of potassium or ammonium ferric phosphates. Strengite and variscite, which are generally recognized to be the forms in which iron and aluminium phosphates occur in soil, are completely resistant. The monovalent metals, sodium and potassium, are liberated in small amounts from muscovite (10 per cent) and pectolite (18 per cent) respectively.

The solubilizing action of a bacterial strain seems to be directly related to the degree to which it can convert glucose into 2-ketogluconic acid. The strain used in most of these tests, which tolerates the consequent high acidity better, was twice as effective as a strain of *Pseudomonas fluorescens*, and about three times as effective as some similar bacteria isolated from rock surfaces.

By choosing soils known to be rich in minerals containing calcium and magnesium it could be shown that the solubilizing action of the cultures was exerted under soil conditions. It was also found that the bacteria would liberate appreciable amounts of the metals from iron and manganese pans.

Accounts of both these researches were given to the Fifth International Congress of Biochemistry at Moscow in August. Reports on various other topics [13, 36, 46] have been published or accepted for publication.

PLANT PHYSIOLOGY

The work of the department has proceeded satisfactorily, a feature of the year's work being the increasing association with other departments. Progress in the construction of the new laboratories has been closely followed.

During the year Dr W. M. Crooke transferred to the department of Soil Fertility. Dr I. R. MacDonald spent the year at the Department of Plant Biochemistry, University of California, Los Angeles, continuing work on anion absorption. Research workers from several countries visited the department for extended periods.

Interaction between Major and Trace Elements. Since it is apparent that earlier work on iron deficiency and its effect on the mineral composition of the leaf is becoming generally recognized, the work has been extended to include the trace elements manganese and copper, and extensive experiments on the relation between these elements and iron have been carried out. Experiments are still in progress. Records of field work in the department are also being examined, and although work is at an early stage it is apparent that for a number of plants under varying conditions of nutrition the results support the concept of an iron-manganese ratio in plants. Studies on nutrient deficiencies in forest stands have been commenced with the section of Forest Soils.

Cation-Anion Balance. An apparatus for the growth of plants in very dilute nutrient solutions has been constructed, employing a simple air lift from a large storage bottle and an intermittent syphon to return the nutrient solution from the crocks. It has been found that root growth is greatly stimulated in dilute solutions, and the greater amount of root material obtained will allow comparison with the mineral composition of the leaf and stem. From the results so far obtained it appears that the interaction of phosphorus, iron, potassium and calcium holds equally well in very dilute solutions, even although the total content of minerals in the leaf is depressed. Further studies on variation of the major cations in the nutrient solutions and its effect on the cation and anion composition of leaves are in progress. Work on the organic acid composition of leaves has continued in collaboration with the department of Biochemistry, and results of work on aconitase activity[11, 12] have been published.

Metabolic Changes in Storage Tissue Disks. Papers have now been published on changes in pectin content[14] and metabolic processes associated with growth[15] in storage tissue disks.

Cation-Exchange Properties of Plant Roots. Work on the cation-exchange properties of plant roots continues, and the results concerning cation-exchange capacity-pectin gradients along the root have now been published[16].

Last year it was reported that some 80 species of natural vegetation had been sampled from four soil types as part of the study of the root cation-exchange capacity—pectin relationship. Statistical examination of the

results for the 12 species common to all four soil types has shown that the relationship is independent of substrate, *i.e.*, the line obtained by plotting the cation-exchange capacity (C.E.C.) of the roots against their pectin (uronic acid) content is the same whether the plants were growing on sand, peat, acid soil or calcareous soil. The results also show that the cation-exchange capacity is a characteristic of a species.

These results for higher plants have been supplemented by data obtained for marine algae, mosses, ferns and fungi, and for single samples of *Equisetum* sp., soil bacteria, yeast, liverwort and lichen. In these the exchange capacity of the tissue and its uronic acid content were found to be similarly related. A paper on this work has been accepted for publication[38].

Chemical analysis of natural vegetation has been carried out and the results examined to see whether the root C.E.C. influences the mineral composition of the plant. Good correlations were found between root C.E.C. and total cations in the leaves, and between C.E.C. and ash and excess base (the fraction of total cations balancing organic acids in the plant).

Application of these findings to published data for crop plants and natural vegetation has confirmed the relationships. In the first case C.E.C. values published by other workers were used, and in the second C.E.C. values measured in this laboratory for plants growing in Scotland were linked with mineral analyses for the same species of plant grown in Germany. An account of this aspect of the work has been accepted for publication[39].

In this work it has been noticeable that high root C.E.C. and high cation and trace element content appear to go together. The natural division of plants into monocotyledons and dicotyledons is reflected in the low C.E.C. and cation content of the former and the higher C.E.C. and cation content of the latter. Within the dicotyledons there is some suggestion that the more primitive members on the evolutionary scale have a low C.E.C. and the more advanced members a rather higher one.

Although the samples of natural vegetation taken in 1960 embraced 80 species, only some 24 families were represented. The main effort in 1961 has therefore concentrated on building up a collection of root and top samples representative of as many families as possible. The number of families represented has now increased to 98 and species to about 400. Chemical analysis is still in progress.

RADIOACTIVITY

The method of placement of radioactive isotopes at different depths n peat has been improved by construction of an apparatus to accurately guide the probe through which the solutions are injected. The method of dispensing isotopes in the field has been made easier and safer by use of a closed pumping system. A description of the method has been prepared for publication. Further work on the depth of rooting of plants in peat which has been cultivated to different depths has been carried out in collaboration with the section of Peat Ecology.

Soil phosphate studies, in pot experiments, have been continued with the department of Soil Fertility.

MICROBIOLOGY

The general aims of the department are (a) to investigate the role of soil micro-organisms in the decomposition of soil organic matter and the breakdown of naturally occurring minerals, (b) to study the relationship between soil micro-organisms and the roots of higher plants with special reference to the solubilization of difficultly soluble phosphates, and (c) to carry out detailed studies on the more important organisms involved in (a) and (b) above. As in the past, collaboration with the departments of Biochemistry, Soil Fertility, Spectrochemistry, and Pedology has been maintained.

Miss L. M. Thubron joined the staff in August 1961 to take up the study of phosphate-dissolving micro-organisms in the root region of plants.

Phosphate-dissolving Micro-organisms. The improved plate technique devised in the department and described in detail in a paper[40] to appear in the Transactions of the Seventh International Congress of Soil Science continues to be used as a basis for the initial detection of phosphate-dissolving micro-organisms in soil and the root region of plants. It is further supplemented with direct analyses, by the department of Soil Fertility, of the soluble phosphate liberated from difficultly soluble phosphatic compounds and, by the department of Spectrochemistry, of the metal ions brought into solution by individual isolates. A number of rock phosphates, as well as a range of synthetic iron and aluminium phosphates (kindly donated by Dr Huffman of the Tennessee Valley Authority, U.S.A.), have been examined. So far those bacteria which produce 2-ketogluconic acid (*see* Annual Report 1959-60) are by far the most active bacterial dissolvers of these substances. The iron and aluminium-containing compounds proved to be much more difficult to solubilize than calcium phosphates. Further, the presence of fluorine in rock phosphates adversely affected their solubilization by these bacteria.

An oxalic acid-producing strain of *Aspergillus niger* was active in solubilizing the synthetic iron and aluminium phosphates. The presence of fluorine in the rock phosphates was again found to affect adversely their solubility by this fungus and by other species.

Last year it was reported that when unplanted, partially sterilized soil containing glucose was inoculated with a 2-ketogluconic-producing bacterium this acid appeared in the soil on incubation. This work has been extended by studying the effect of burying pellets containing glucose in the soil. A technique has been worked out for making pellets of varying composition. It has been found that 2-ketogluconic acid is produced in the vicinity of such glucose-containing pellets when buried in a rich unsterilized, uninoculated garden soil which had been incubated for 2-4 days. This suggests that some enrichment of 2-ketogluconic-producing organisms is taking place around the buried pellets in this particular soil. The technique is also being used to study localized bacterial development in soil.

Soil Micro-organisms and the Weathering of Minerals. The details of a

plate method for studying the breakdown of synthetic and naturally occurring silicates[4] have been published. Investigations have been carried out on the chelation of a number of divalent metals (calcium, manganese, zinc, strontium and nickel) and iron and aluminium extracted by microbiological action from a wide variety of synthetic and naturally occurring silicate minerals. The combination of small scale growth experiments, paper chromatography and spectrometric methods of analysis has proved very valuable in this study. Determination of soluble silicate by the department of Biochemistry has shown that a certain amount of this ion appears in the culture fluid from growth experiments with crystalline minerals and soils. A preliminary account of this work in the form of a joint communication with the department of Biochemistry was presented by Dr R. B. Duff at the Fifth International Congress of Biochemistry held in Moscow in August 1961.

A survey of the bacterial and fungal flora of a sequence of rock surfaces and the interior of weathered stones is being carried out in collaboration with the department of Soil Survey. Various methods of assessing the microbial population are being tried. Preliminary results show that the bacterial and fungal flora increase as the colonization of rocks with lichens takes place; also there are considerable numbers of bacteria present in material scraped from inside weathered stones taken from profiles, etc.

Lignin Decomposition. The study of the metabolism of lignin-related aromatic compounds by several hyphomycetes and yeast-like fungi has been extended by using crude cell-free extracts from one of these organisms, *Pullularia pullulans.* Extracts prepared from cells which had previously been adapted to those aromatic compounds which are metabolized through protocatechuic acid were found to possess protocatechuic acid oxidase activity. Such activity was absent from cells exposed to compounds which are not metabolized through protocatechuic acid. Therefore, by examining the activity of cell extracts it was possible to obtain information about the pathway of metabolism of various compounds. In this way it was demonstrated that vanillin is metabolized through protocatechuic acid while syringic acid is not. Since vanillin is closely related to lignin and can be released biologically from it, as demonstrated in this department, the metabolism of lignin is thus linked with protocatechuic acid which is itself a focal point in the metabolism of aromatic compounds. The results of this work have been published[20, 21].

The metabolism of certain lignin model compounds by *Polystictus versicolor* has been studied in collaboration with the department of Spectrochemistry, and the results have been published[10]. The paper on the influence of trace elements in the metabolism of aromatic compounds[22], reported last year, has appeared.

Mineral Metabolism of Soil Nocardias

The study of the physiology of iron, zinc and manganese deficient cells of *Nocardia opaca* has continued. The results obtained are being prepared for publication.

SOIL FERTILITY

The research programme continues to be specifically directed towards the improvement of manurial practice and crop production through better understanding of: (1) the nutrient relationships in different soil types, (2) the fertilizer requirements of different crops, (3) the significance of soil properties, pedological factors and environmental conditions, and (4) the effectiveness of different types of fertilizers, with particular reference to the influence of time, frequency and method of application. The experimental approach therefore remains the concurrent development and integration of field, pot and laboratory studies covering different soil groups and the main agricultural crops. The field experiments are distributed at centres chosen in consultation with the department of Soil Survey and are designed and evaluated with the assistance of the section of Statistics. About 70 experiments are carried out every year, and grateful acknowledgement is again made to the farmers concerned for their willing and efficient co-operation. The pot experiment programme, based on some 600 Mitscherlich type pots, forms an essential supplement to the field work and a link with laboratory studies on the different soil types. In addition to providing the required practical characterization of nutrient relationships, fertilizer requirements and crop responses, these integrated studies on contrasting soils are designed to delineate the pivotal properties which govern the behaviour of the soils and underlie the varying influences of parent material and drainage conditions.

Research findings are translated into practice through the medium of consultative activities, including advisory soil testing in collaboration with the North of Scotland College of Agriculture. The practical implications of results also continue to be dealt with in contributions to the agricultural press and lectures to agricultural and horticultural societies and other technical organizations, while the potential for greater fertilizer usage in Scotland was assessed in a paper[41] read at the annual conference of the Institute of Corn and Agricultural Merchants in Edinburgh. The department continues to be represented on the Field Trials and Grassland Committees of the Scottish Agricultural Improvement Council and the Scottish Sub-Committee of the Sugar Beet Research and Education Committee, and co-operation has been maintained with the Agricultural Research Council Unit of Statistics in the preparation of reports on the Survey of Fertilizer Practice carried out by the Scottish Colleges of Agriculture. Collaboration has also continued with the Hill Farming Research Organisation, the Animal Diseases Research Association, the Rowett Institute and other research and technical bodies.

Mr R. J. Hance, Ministry of Agriculture, Fisheries and Food Research Scholar, has completed a three-year research project on soil phosphorus relationships with special reference to the organic fraction, for which he has been awarded the degree of Doctor of Philosophy by the University of Aberdeen. During a shorter stay of about nine months, Dr S. M. Bromfield,

Division of Plant Industry, Commonwealth Scientific and Industrial Research Organization, Canberra, Australia, studied the evaluation of reactive iron in soils by microbial reduction.

Dr E. G. Williams lectured on soil phosphate relationships in Spain, Norway, Finland and Sweden. The visit to Spain was under the auspices of the Consejo Superior de Investigaciones Cientificas, and lectures were given at the Instituto de Edafologia y Fisiologia Vegetal, Madrid, and the Inorganic Chemistry Department of the University of Seville. In Scandinavia lectures were delivered at the Agricultural College of Norway, Vollebekk, the Department of Agricultural Chemistry of the University of Helsinki, and the Royal Agricultural College of Sweden, Uppsala, at the joint invitation of the Rectors of these institutions. These visits provided most valuable and stimulating opportunities for visiting research centres and developing personal contacts with numerous colleagues in the different countries, and grateful acknowledgement is made not only of the honour conferred but also for the most kind reception and generous hospitality.

Drs J. W. S. Reith and G. Anderson attended the joint meeting of the Soil Science Society of Ireland and the British Society of Soil Science in Dublin, and Dr Reith also attended a discussion in London on alternative nitrogen fertilizers, organized by the Agricultural Group of the Society of Chemical Industry.

The senior research staff has been increased by the transfer of Dr W. M. Crooke from the department of Plant Physiology.

Crop Responses to Fertilizers. Factorial NPK field experiments to measure responses and two-factor interactions for different crops and soils have been continued. The results from this series of experiments are being used by the section of Statistics to find an equation for the response surface and to determine whether such an equation can give a satisfactory prediction of optimal fertilizer rates. Further experiments to examine in more detail the effects of farmyard manure on the responses of swedes to nitrogen and phosphate have also been carried out, and an account has appeared of the yield results from the regional grassland manuring experiments co-ordinated by the Grassland Committee of the Scottish Agricultural Improvement Council[23] and summarized in last year's report.

Methods and Times of Fertilizer Application. Further experiments on the time of application of nitrogen for barley, and on the comparison of broadcast and band applications of different phosphate fertilizers for oats, barley and swedes grown in ridges have been carried out. The experiments on the last crop included preliminary tests on the broadcasting and placement of triple superphosphate solution compared with the solid form.

Trace Elements. Field and pot measurements of the residual effects of copper and cobalt dressings have been continued, with special reference to the composition of grasses and clovers, the supplementary analytical work being carried out by the department of Spectrochemistry. Experiments with cereals indicate that a dressing of 20 lb. copper sulphate per acre can be expected to be effective in correcting copper deficiency for at least six years.

Magnesium and Calcium. Attention continues to be given to the magnesium status of different soils and crops, with particular reference to the effectiveness of different types of magnesium supplements and the influence of different levels of manuring with nitrogen and potassium. An article outlining the role of lime in the maintenance and improvement of soil fertility in Scotland[24] has appeared, and a paper summarizing the long-term effects of a range of liming materials[42] is in press.

Nitrogen. The paper on the interrelationships of total nitrogen with carbon, sulphur, and organic phosphorus in soils derived from different parent materials[25], mentioned in last year's report, has now appeared, and progress has been made with a complementary study of the effects of drainage conditions. Field work designed to estimate the fixation of atmospheric nitrogen by clover in the absence and presence of fertilizer nitrogen has been continued, and further comparisons of urea in solution and solid form with fertilizers based on ammonium nitrate have been carried out on barley.

Potassium. Characterization of the potassium status of different soil types, of the requirement of different crops, and of the interactions of potassium with other nutrients has been continued, and two field experiments have been laid down to examine the effects of potassium applied as the chloride, sulphate, bicarbonate and nitrate on the yield and dry matter contents of potatoes.

Inorganic Phosphate. Field and pot studies have been continued on the residual value of heavy dressings of superphosphate and rock phosphate in different soil types, and on the effectiveness on different crops of a range of phosphate fertilizers of varying solubility and particle-size, including triple superphosphate in solid and solution form, mono- and di-ammonium phosphate, dicalcium phosphate, granular and powdered basic slag, and over twenty different types of rock phosphate. Progress has been made with the evaluation of results from a series of long-term experiments, now largely completed, on the time of application of phosphate and the significance of ploughing and cultivation in relation to the dispersion and positional availability of phosphate residues and fresh dressings.

Complementary laboratory studies on phosphate retention, distribution and solubility in different soil types have been continued. An account of some of these studies, covering the varying influences of soil parent material and drainage conditions[43], is in press, and together with selected results from relevant field and pot experiment investigations these formed the main basis of the lectures on soil phosphate relationships, mentioned earlier, which were given in Spain and Scandinavia. Related studies on the distribution of reactive aluminium and iron have also been continued, and in this connection Dr S. M. Bromfield, visiting worker from the Division of Plant Industry, C.S.I.R.O., Australia, carried out a supplementary investigation of the extraction of iron and incidental removal of aluminium by techniques based on microbiological reduction.

Organic Phosphate. A paper on the estimation of purines and pyrimidines in soil humic acid[26] has appeared, and an account of further studies on the determination of total soil organic phosphate has been prepared for publication. In the latter investigation an ignition method and three extraction procedures were compared over 34 Scottish soils. The ignition values were usually greater than the highest extraction values, but for more than half of the soils the differences were small and unimportant. There is no direct evidence that any of the ignition values are erroneously high, and since the ignition method is rapid and easy to carry out it is considered to be the most useful for the general analysis of Scottish soils.

To clarify the factors governing the solubility and extraction of phosphate esters in soils, their reaction with other soil constituents has been studied in a wide range of acid media. Certain hydrated oxides of iron and aluminium and a sesquioxide-rich soil clay adsorbed inositol phosphates and glycerophosphate strongly, even under very acid conditions. Montmorillonite adsorbed considerable quantities of inositol hexaphosphate at pH 4, but X-ray examination gave no indication that an ordered clay-organic complex was formed. An account of this investigation has been prepared for publication, and a paper on the partial fractionation of alkali-soluble soil organic phosphate[44] is in press. Other papers in preparation cover the estimation of phospholipids in soils and the identification of their hydrolysis products.

Further work has been done on the influence of Fe/P ratio on the precipitation of ferric phytate in acid solutions and its significance in relation to the estimation of phytin in plant and soil extracts. Other studies in progress include collaborative work with the department of Microbiology on the effect of trace metal deficiency on the nucleic acid content of the soil actinomycete *Nocardia opaca.*

Sulphur. A specific programme on the sulphur status of different soils and crops is being developed, and to cover the trend towards increasing purity in commercial fertilizers a field experiment has been started to measure the effects of incremental sulphur dressings compared with sulphur-free fertilizer combinations and the incidental additions from normal fertilizer mixtures.

Advisory Activities

The department continues to undertake advisory analysis of soils, crops, liming materials and composts. During the year 11,300 soil samples, taken mainly from agricultural land by the staff of the North of Scotland College of Agriculture were examined. Collaboration with the section of Forest Soils in the analysis of soils from forest nurseries has been maintained, while special problems concerning animal health and crop production continue to be dealt with in conjunction with the departments of Spectrochemistry and Plant Physiology, the most common troubles being deficiencies of cobalt, copper or manganese, or an excess of molybdenum. There is still no convincing evidence of any yield restrictions attributable to magnesium deficiency, but there is a steadily growing demand for magnesium analyses in relation to animal health. In over 50 per cent of the fields examined the

indications are that dressings of the order of 4 cwt. MgO per acre can be expected to increase substantially the magnesium contents of crops and pasture. The records for samples examined during 1960 show that the general improvement in the lime status of soils in the north of Scotland is being maintained, but there is little change in the general distribution of their phosphate and potash contents.

STATISTICS

The statistical service which the section provides for the Institute is based on the research programmes of other departments, and results derived from analyses carried out in the section of Statistics will be recorded in the reports of these departments. Collaboration has been increased, particularly with the section of Forest Soils, both in the analysis of experimental results and in the design of experiments. The main work of the section, however, continues to arise from the field experiment programme of the department of Soil Fertility.

This programme contains almost equal numbers of experiments commenced during 1961 and continued from previous years. Some are concerned with measurements of crop composition and soil characteristics as well as measurements of crop yield. The experimental designs used include randomized blocks, split-plot randomized blocks, Latin squares, factorial designs with and without confounding, factorial designs with fractional replication, and lattice squares. The analysis of 43 variates from 12 field experiments of various designs was carried out on the Elliott 401 electronic computer. Acknowledgement is due to the Department of Statistics of Rothamsted Experimental Station for the facilities made available in this respect, and also to the Agricultural Research Council Unit of Statistics for the use of teleprinter equipment by which means the data and instructions were transferred to punched tape.

Work is in progress on measurements of the chemical composition of herbage from a series of grassland regional manurial experiments co-ordinated by the Grassland Committee of the Scottish Agricultural Improvement Council. An account of the yield data from the series[23], prepared in collaboration with the department of Soil Fertility, has been published.

A paper which explains and discusses alternative methods of analysis of $3^2 \times 2^2$ and $3^3 \times 2$ factorial experiments[45] has been accepted for publication. The methods were illustrated on two particular series of experiments and it was confirmed that conclusions based on one method of analysis were not invalidated by the other.

Randomized blocks and factorial designs have been used for a number of experiments planned in collaboration with the section of Forest Soils. The majority of experiments for which reports on the results have been made are of factorial design with two or three factors, and there were also Latin squares and a plaid square design. Where new treatments are superimposed on an existing experiment split-plot arrangements have been used. The data examined were annual height or girth increments and foliage analysis measurements.

A number of experiments designed and analysed in collaboration with the department of Plant Physiology were concerned with periodic readings of catalase and peroxidase. The results for catalase are expressed in terms of the rate of reaction which is proportional to the activity of the enzyme and

is estimated by fitting an exponential curve to the data. A study of the relationship between the uronic acid content and the cation-exchange capacity of plant roots showed that the data could be adequately represented by a single straight line although the data were obtained from a range of natural vegetation and a number of growth media. An account of this work[38] has been accepted for publication. A study has also been made of the correlations between a number of other properties and the cation-exchange capacity and the ash of plant roots. Further experiments have been designed to test the effects and interactions of the factors Fe, K/Ca and P/N on the composition of mustard leaves.

The logarithmic transformation was used in order to show the constancy of certain ratios in the measurements of aconitase activity, an investigation carried out on behalf of the department of Biochemistry.

A considerable number of analyses of variance and tests of significance were undertaken in a study of the trace element content of laminae and leaves of deciduous trees.

The analysis of data and reporting of results from NPK factorial experiments on potatoes is being continued on behalf of the Crop Husbandry Department of the West of Scotland Agricultural College. Eighteen variates from three single replicate 3^3 experiments on main crop potatoes were analysed on the electronic computer at Rothamsted. Two early crop experiments had three dates of lifting as an additional factor applied as a sub-plot treatment in order to investigate the rate of bulking of the early potato crop. Further series of experiments, based on the 3^3 factorial design, have been planned for potato and swede crops.

Collaborative work with the Entomology Department of the North of Scotland College of Agriculture has included the analysis of a randomized block experiment testing insecticides for the control of wheat bulb fly. The angular transformation was used in the analysis of measurements on crop damage. A series of split-plot experiments on the control of carrot fly has been concluded and an account of the results[27] has been published in a joint paper.

The section is at present accommodated in the Department of Statistics of the University of Aberdeen, where a course of statistical technique lectures on biometric practice in forestry has been given to Honours degree students. Acknowledgement is made to the University of Aberdeen, and in particular to Dr D. J. Finney, F.R.S., for courtesies shown.

LIBRARY

The Institute maintains a small specialized library with a stock covering most branches of soil science and related fields of interest. Its main function is to provide a reference and loan service for the staff of the Institute, but material is lent to other libraries and to individuals. Loans can be obtained either on direct application or through the national inter-library lending schemes in which the Institute participates and which are extensively used in borrowing books and journals required by members of staff.

Exchange arrangements are welcomed, and annual reports and reprints of papers published by members of staff are supplied free of charge to anyone interested in the research activities of the Institute. Lists of available reprints are issued, and arrangements can be made for anyone wishing to receive these to be placed on the mailing list.

This year the library was transferred to the new building and established in an attractively designed room 50 ft. long × 30 ft. wide. Books and journals are accommodated in wall shelves and double-sided island stacks, and the maximum use of floor space has been ensured by the introduction of a gallery running the length of the room on one side. This has made it possible to confine the shelving to one half of the library, leaving the other completely free for the reading tables which can be readily removed to provide seating space for meetings and lectures. Tall windows along one wall give good natural lighting.

The improved accommodation includes an office and a small workroom for the routine library tasks which formerly had to be carried out in the library itself. Better facilities are available for reading and study, and the easing of the shelving problem has meant that stock is now properly displayed and readily accessible to borrowers.

PUBLICATIONS

(A) *Published—*

1. Problems associated with high sensitivity of recording in differential thermal analysis. By B. D. Mitchell. (*Clay Min. Bull.*, **4**, 246-248, 1961.)

   Differential thermal analysis has proved of great assistance in the investigation of soil clays and plant materials, particularly when the apparatus is of high sensitivity. The factors enabling such high sensitivity to be obtained without loss of accuracy are briefly discussed.

2. Some interstratified clay minerals from basic igneous rocks. By Wilma W. Smith. (*Clay Min. Bull.*, **4**, 182-190, 1960.)

   Fresh samples of some Scottish basic igneous rocks contain two-component interstratified minerals, which consist mainly of layers of chlorite, swelling chlorite and saponite in different combinations. The differential thermal curves are characteristic of swelling chlorite.

3. Structural relationships within pseudomorphs after olivine. By Wilma W. Smith. (*Miner. Mag.*, **32**, 324-331, 1959.)

   The orientational relationships between alteration products in pseudomorphs after olivine from Dunsapie basalt have been studied. The principal axes of the minerals in the pseudomorphs, *viz.*, saponite, goethite, and hematite, are parallel to each other and their arrangement is influenced by their structural characteristics.

4. A plate method for studying the breakdown of synthetic and natural silicates by soil bacteria. By D. M. Webley, R. B. Duff and W. A. Mitchell. (*Nature*, **188**, 766-767, 1960.)

   An account is given of a plate technique for studying the breakdown of synthetic and natural silicates by soil micro-organisms. It has been shown by X-ray analysis that the crystalline structure of certain naturally occurring minerals is destroyed through the action of 2-ketogluconic acid which is produced by certain soil bacteria. Such organisms may therefore play a role in the biological weathering of naturally occurring minerals.

5. The response of some hill pasture types to lime and phosphate. By R. A. Robertson and I. A. Nicholson (Hill Farming Research Organisation). (*J. Brit. Grassl. Soc.*, **16**, 117-125, 1961.)

   A study was made of the response of four upland soil and vegetation types to applied lime and phosphate in the north of Scotland. Light and heavy dressings were used, the former being at a rate which might be economically considered for aircraft application. Two experiments were laid down on graminaceous communities and two on contrasting types of *Callunetum*. The low rate of lime produced little measurable soil response, whereas the high rate induced marked and persistent effects. In terms of botanical response, however, the high rate of liming showed little advantage over the low rate in the presence of phosphate at the two grassland sites. Only very minor vegetation effects were observed at the *Calluna* centres, particularly where the dominant was in a mature stage of development. The results emphasize the importance of an ecological approach to upland pasture improvement involving a knowledge of the specific responses of different plant communities to fertilizer application, combined with an appropriate measure of stock control.

6. Evidence regarding rate of peat growth. By S. E. Durno. (*J. Ecol.*, **49**, 347-351, 1961.)

   Pollen analytical and peat stratigraphical results from mosses in the north-east of Scotland have been used to estimate rates of peat growth.

7. Trace-element distribution in soil profiles. By D. J. Swaine and R. L. Mitchell. (*J. Soil Sci.*, **11**, 347-368, 1960.)

The contents of total and extractable trace elements present in Scottish soil profiles are primarily related to the geological parent material from which the soils are derived. Little or no effect within the profile attributable to pedological factors has been observed in the total contents. The most marked effect on the contents of extractable trace elements, notably Co, Ni, Cu, Mn, Mo, Zn and Pb, is their increased mobilization in conditions of restricted drainage. Very high extractable contents occur in gleyed horizons of very poorly drained soils. No marked accumulation of trace elements has been observed in the iron pan or illuvial horizons of podzolized profiles. Higher contents of acetic acid extractable Al occur in soils with unrestricted drainage, the amounts present being of the same order as the exchangeable Ca contents.

8. Application of direct photometry to agricultural analysis. By R. O. Scott. (*J. Sci. Food Agric.*, **11**, 584-592, 1960.)

The applications of two direct-reading spectrometers to the analysis of agricultural materials are described. The first is a two-channel instrument for the determination of magnesium in solution by the porous-cup spark method. The second is the eleven-channel Hilger Medium Direct Reader with which Cu, Mn, and Zn are determined in soil extracts by the porous-cup spark method. A tentative pelleted rotating disk method is also described for the determination of Zn, B, Mn and Cu in ashed plant materials.

9. Contamination problems in soil and plant analysis. By R. L. Mitchell. (*J. Sci. Food Agric.*, **11**, 553-560, 1960.)

The problems arising from contamination in soil and plant analysis are important chiefly in trace element work and originate either during the sampling and preparative stages or in the laboratory. With soils the chief danger occurs during transport in unsuitable containers or during drying and sieving. Plants are liable to be contaminated by soil, and means of assessing its severity and its possible effect on analytical results by determination of the apparent Ti content of the plant material are described. Contamination arising in the laboratory can be minimized by stringent precautions at all stages of the work, and by the use of carefully selected and, if necessary, purified reagents.

10. Metabolism of lignin model compounds by *Polystictus versicolor*. By J. D. Russell, Moira E. K. Henderson and V. C. Farmer. (*Biochim. Biophys. Acta*, **52**, 565-570, 1961.)

Under the influence of soil micro-organisms, plant lignins undergo modification and decomposition, leading to products which forms an important part of soil organic matter. Neither the mechanism of the initial cleavage of the lignin molecule, nor the enzyme systems involved are understood. In an attempt to clarify this problem a study has been made of the lignin model compounds α-veratrylglycol-β-guaiacyl ether I, α-veratrylglycerol-β-guaiacyl ether II, α-guaiacylglycol-β-guaiacyl ether III and α-guaiacylglycerol-β-guaiacyl ether IV. Mats of the fungus *Polystictus versicolor* metabolized compounds III and IV, but not compounds I and II. Veratryl alcohol was formed from III. Veratraldehyde and veratryl alcohol were also formed when solutions of p-hydroxybenzoic acid, protocatechuic acid, vanillin and vanillyl alcohol were metabolized by the fungus. Smaller amounts of veratraldehyde were liberated by the growing fungus and by preformed mats. None of the model compounds I to IV was oxidized by the aromatic-alcohol oxidase of *P. versicolor*.

11. The measurement of aconitase activity in the leaves of various normal and variegated plants. By J. S. D. Bacon, M. J. Palmer and P. C. DeKock. (*Biochem. J.*, **78**, 198-204, 1961.)

In order to test the hypothesis that iron-deficiency depresses the activity of certain

enzymes in the leaf a method of measuring one of them, aconitase, in 0·5 g. samples has been developed by modifications of a spectrophotometric procedure first used for animal tissues. The optimum conditions for extraction and assay have been examined in detail. The validity of results obtained by the method is discussed, and examples are given of measurements on the leaves of a variety of plants, including several of economic importance.

12. Aconitase levels in the leaves of iron-deficient mustard plants (*Sinapis alba*). By J. S. D. Bacon, P. C. DeKock and M. J. Palmer. (*Biochem. J.*, **80**, 64-70, 1961.)

A method for measuring the activity of the enzyme aconitase in extracts of leaves has been applied to mustard plants grown in solution culture. In iron-deficient plants the activity was only half that in normal ones. Variations in the levels of various other nutrients had only slight or irregular effects. Two other enzymes which are closely associated with aconitase in the metabolism of the leaf were not depressed by iron-deficiency. When iron was fed to deficient plants, or to leaves detached from them, the aconitase level was restored to normal in a few days, but no means was found of restoring the activity in extracts of the leaves, suggesting that the lower activity is due to a lack of the whole enzyme and not simply of iron.

13. The oligofructosides. By J. S. D. Bacon. (*Bull. Soc. Chim. biol.*, **42**, 1441-1450 and 1467-1474, 1960.)

The oligofructosides, which have the general character of polyfructosyl derivatives of sucrose, occur for the most part in plants. Three trisaccharides of this type have been identified, each based upon the substitution by a β-fructofuranosyl group of one of the three primary alcoholic groups of sucrose. The biochemistry of these trisaccharides, and of higher oligosaccharides like them, is discussed in relation to sucrose on the one hand, and to fructosans (inulins, levans, etc.) on the other. Four categories of plants are distinguished; two, the monocotyledons and the inuliferous plants, are discussed in detail from the point of view of the origin and metabolic significance of the oligofructoside fraction. Despite the agricultural importance of many of the plants concerned (*e.g.*, grasses, cereals) our present knowledge is scanty, and does not yet permit us to reach any firm conclusions.

14. Changes in the pectin (uronic acid) content of storage tissue disks. By A. H. Knight, W. M. Crooke, I. R. MacDonald and H. Shepherd. (*J. exp. Bot.*, **12**, 13-26, 1961.)

Pectic substances in fruits and storage organs alter markedly during ripening and maturation. As part of the general investigation of metabolic processes in disks of storage tissues the changes in pectin content have been studied. Disks of carrot, swede, turnip, sugar beet, red beet and potato were maintained in aerated, running tap water at three temperatures for periods of up to 20 days. Under certain conditions, pectin is synthesized and there are changes in the relative amounts of water-soluble and water-insoluble constituents of the tissues.

15. Metabolic processes associated with growth in storage tissue disks. By I. R. MacDonald, A. H. Knight and P. C. DeKock. (*Physiol. Plant.*, **14**, 7-19, 1961.)

Investigations on the metabolism of disks of storage tissue have proved useful in suggesting probable metabolic pathways in storage roots. It has been shown that in disks of sugar beet, red beet, carrot and swede maintained in running tap water there is an increase in the content of organic compounds of nitrogen and phosphorus. Protein synthesis is promoted by the presence of free nitrate in the tap water. It is concluded that the metabolic changes occurring in the disks are most accurately characterized in terms of renewed growth.

16. Cation-exchange capacity and pectin gradients in leek root segments. By W. M. Crooke, A. H. Knight and I. R. MacDonald. (*Plant and Soil*, **13**, 123-127, 1960.)

Cation-exchange capacity, pectin, respiration, and nitrogen content have been

measured in successive segments of leek roots over a distance of 140 mm. from the root tip. All are highest at the root tip and decrease with increasing distance from the root tip.

17. Mineral content of plant leaves. By P. C. DeKock. (pp, 1039-1042 of *Biochemists Handbook*. Edited by C. Long. Spon, 1961.) (*No reprints*).

Tables of major and trace elements contained in the leaves of various plants.

18. Trace elements in plant nutrition. By P. C. DeKock. (pp. 1-11 of *Some Aspects of Trace Elements in Nature*. Symposium edited by K. H. Schütte. University of Cape Town: Botany Department. 1961.)

A review article.

19. The Macaulay Institute for Soil Research. By A. B. Stewart. (*Scot. Young Fmr.*, **9**, No. 1, 13-15, 1961.) (*No reprints*).

20. Isolation, identification and growth of some soil hyphomycetes and yeast-like fungi which utilize aromatic compounds related to lignin. By Moira E. K. Henderson. (*J. gen. Microbiol.*, **26**, 149-154, 1961.)

The decomposition of lignin by fungi, which is an important constituent of soil organic matter, has been further investigated. The present studies have added to the list of soil organisms known to attack lignin-related compounds and have emphasized the possible role of micro-organisms in the decomposition of lignin under natural conditions. The fungi which were used were isolated from soil under several vegetational types by means of an enrichment technique in which aromatic compounds related to lignin were employed as substrates. The isolates were members of the yeasts and hyphomycetes and were different from those previously obtained in this Institute by the dilution plate technique. Representative species were found to be able to utilize several aromatic compounds as sources of carbon.

21. The metabolism of aromatic compounds related to lignin by some hyphomycetes and yeast-like soil fungi. By Moira E. K. Henderson. (*J. gen. Microbiol.*, **26**, 155-165, 1961.)

In continuation of studies on the decomposition of components of soil organic matter, investigations were made into the metabolism of lignin-related aromatic compounds by soil yeasts and hyphomycetes. These organisms had previously been shown to be able to grow on such compounds. Oxygen uptakes, the production of intermediate metabolic products and enzyme activity in crude cell-free extracts from adapted cells were used to elucidate metabolic pathways. Protocatechuic acid was a common intermediate metabolic product for several of the compounds. With its decomposition all trace of aromatic structure disappeared. Thus a possible pathway of metabolism for aromatic units released from lignin to the stage at which the aromatic structure is lost has been demonstrated.

22. The influence of trace elements on the metabolism of aromatic compounds by soil fungi. By Moira E. K. Henderson. (*J. gen. Microbiol.*, **23**, 307-313, 1960.)

The role of the trace elements Cu, Fe, Mn and Zn on the metabolism by soil fungi of compounds related to lignin has been investigated. The compounds studied were: *o*-, *m*- and *p*-hydroxybenzoic, *o*-, *m*- and *p*-methoxybenzoic, 3:4-dimethoxybenzoic and vanillic acids and catechol. Only a deficiency of iron was found to have a marked influence on their metabolism and led to the initial accumulation of intermediate products of metabolism. The identification of these intermediates has thrown further light on the pathways by which lignin can be broken down by biological means.

23. The effects of fertilizers on herbage production. Part I. The effect of nitrogen, phosphate and potash on yield. By J. W. S. Reith and R. H. E. Inkson and collaborators. (*J. Agric. Sci.*, **56**, 17-29, 1961.)

The paper reports the results of six factorial experiments carried out over a period of three years, and designed to measure the effects of nitrogen, phosphate and potash on the yield of dry matter and to determine the effect of nitrogen on the phosphate and potash requirements of grass being regularly cut for conservation. The response to nitrogen, especially at the highest rate of 348 lb. N per acre per annum, depended on an adequate supply of potash. There were large interactions between these two nutrients and the need for potash was much greater in the second and third than in the first year of the experiments. Phosphate had practically no effect on the yield either in the presence or absence of nitrogen. A lb. of fertilizer nitrogen produced considerably more dry matter during May, June and July than later in the season.

24. Lime and soil fertility. By J. W. S. Reith. (*Scot. Agric.*, **40**, 205-208, 1961.)

The paper outlines the various factors that affect the need for lime in Scotland. Although the amount applied has increased almost four-fold during the past 20 years, many soils are still short of lime. The use of magnesian or dolomitic limestone and the effects of over-liming on trace elements are briefly discussed.

25. Carbon, nitrogen, sulphur and phosphorus in some Scottish soils. By C. H. Williams, E. G. Williams and N. M. Scott. (*J. Soil Sci.*, **11**, 334-346, 1960.)

The distribution and interrelationships of organic carbon and total nitrogen, sulphur and organic phosphorus have been studied for five groups of acid soils and one group of calcareous soils in north Scotland. The carbon, nitrogen and sulphur (corrected for sulphate in the calcareous group) are highly correlated in all five groups, which give a mean C:N:S ratio of 140:10:1.4. The relationships of organic phosphorus are more variable suggesting that it is a less integral part of the organic matter than is sulphur.

26. Estimation of purines and pyrimidines in soil humic acid. By G. Anderson. (*Soil Sci.*, **91**, 156-161, 1961.)

It has previously been shown that purine and pyrimidine bases characteristic of deoxyribonucleic acid (DNA) are released from soil humic acid on hydrolysis. To obtain a more accurate assessment of the contribution of this type of nucleic acid to the total soil organic phosphate, an improved method for the quantitative determination of these bases in humic acid has been developed. The method has been applied to a variety of soils, and values for the total bases ranged from 14 to 61μ moles per 100 g. soil. The proportions of the bases indicate that they were probably in the form of polynucleotides derived mainly from bacterial DNA and on this assumption would account for 0.6 to 2.4 per cent of the soil organic phosphate.

27. Trials on carrot fly control in north-east Scotland 1956-58. By M. W. Shaw and R. M. Allan (North of Scotland College of Agriculture) and R. H. E. Inkson. (*Plant Path.*, **10**, 110-115, 1961.)

This paper reports the results of experiments carried out in north-east Scotland during 1956-58 to test the effectiveness of various insecticidal treatments. Split-plot designs were used and, in the analysis of the percentage (p) of undamaged carrots, the angular transformation ($\sin^{-1}\sqrt{p}$) was used. The results show that when a moderate attack occurred the treatments all provided substantial control sufficient to offset any serious deterioration of crop quality due to "fly" injury.

(B) *Submitted—*

28. The general principles of classification with reference to soils. By J. W. Muir. (To appear in *J. Soil Sci.*)

29. The origin of the B_3 horizon of podzolic soils in north-east Scotland. By J. C. C. Romans. (To appear in *J. Soil Sci.*)

30. The quantitative determination of minerals in clays. By R. C. Mackenzie. (To appear in *Acta Univ. Carol., Geol.*)

31. The influence of soil forming factors on clay genesis. By B. D. Mitchell. (To appear in *C. R. Colloque sur la Genèse et la Synthèse des Minéraux Argileux*)

32. The quantitative determination of halloysite, goethite and gibbsite. By R. C. Mackenzie and R. H. S. Robertson (Pitlochry). (To appear in *Acta Univ. Carol., Geol.*)

33. Weathering of some Scottish basic igneous rocks with reference to soil formation. By Wilma W. Smith. (To appear in *J. Soil Sci.*)

34. Peat: its origin, properties and use in horticulture. By R. A. Robertson. (To appear in *Sci. Hort.*)

35. Application of direct-reading spectrochemical methods to soil analysis. By R. O. Scott. (To appear in *Trans. VII Int. Congr. Soil Sci.*)

36. The occurrence of 2-0-methylrhamnose and 4-0-methylgalactose in soil and peat. By R. B. Duff. (To appear in *J. Sci. Food Agric.* **12,** 826-831, 1961.)

37. Effects of natural and synthetic chelating substances on the mineral status of plants. By P. C. DeKock. (To appear in *Trans. VII Int. Congr. Soil Sci.*)

38. Cation-exchange capacities of tissues of higher and lower plants and their related uronic acid contents. By A. H. Knight, W. M. Crooke and R. H. E. Inkson. (To appear in *Nature*)

39. An evaluation of published data on the mineral composition of plants in the light of the cation-exchange capacities of their roots. By W. M. Crooke and A. H. Knight. (To appear in *Soil Sci.*)

40. Evaluation of the plate technique in use for studying phosphate-dissolving micro-organisms. By D. M. Webley. (To appear in *Trans. VII Int. Congr. Soil Sci.*)

41. The potential for greater fertilizer usage. By J. W. S. Reith. (To appear in *J. Inst. Corn Merch.*, **9,** 149-151, 1961.)

42. Long-term effects of various liming materials. By J. W. S. Reith. (To appear in *Emp. J. exp. Agric.*)

43. Some aspects of phosphate retention and availability in soils. By E. G. Williams. (To appear in *Trans. VII Int. Congr. Soil Sci.*)

44. A partial fractionation of alkali-soluble soil organic phosphate. By G. Anderson. (To appear in *J. Soil Sci.*, **12,** 276-285, 1961.)

45. The analysis of a $3^2 \times 2^2$ factorial experiment with confounding. By R. H. E. Inkson. (To appear in *Applied Statistics*)

(C) *Collaborative Work (Foreign)*—

46. Some observations on the form and location of invertase in the yeast cell. By M. Burger (Czechoslovak Academy of Sciences), E. Elizabeth Bacon (Aberdeen) and J. S. D. Bacon. (*Biochem. J.*, **78,** 504-511, 1961)

THESIS

The following thesis has been accepted by the University of Aberdeen for the degree of Doctor of Philosophy.

Soil phosphorus relationships with particular reference to the organic fraction. By R. J. Hance.