THE MACAULAY INSTITUTE FOR SOIL RESEARCH

FOUNDED 1930

1966-1967 ANNUAL REPORT

No. 37

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THE MACAULAY INSTITUTE FOR SOIL RESEARCH

CRAIGIEBUCKLER, ABERDEEN

(Founded 1930)

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J. -F. Bouhours (Laboratoire de Physiologie Végétale, Université Catholique de Toulouse, France).
A. S. Campbell (Soil Science Department, Lincoln College, The University, Canterbury, New Zealand).
B. G. Ellis (Soil Science Department, Michigan State University, East Lansing, Michigan, U.S.A.).
A. S. de Endredy (F.A.O., Rome, Italy).
Mrs Alison Innes (University of Aberdeen Research Scholar).
P. D. Jolodovsky (Laboratorio de Espectroscopia, Instituto Nacional de Tecnologia Industrial, Buenos Aires, Argentina).
S. S. Jørgensen (Agrikulturkemisk Laboratorium, Den Kgl. Veterinaer og Landbohojskole, Copenhagen, Denmark).
F. Megusar (Biotehniska Fakultata, Univerza v Llubljani, Yugoslavia).
Mrs Celia Perez Rodriguez (Estacion Experimental del Zaidin, Granada, Spain).
J. L. Perez Rodriguez (Centro de Edafologia y Biologia Vegetal, Seville, Spain).
J. A. Horta da Silva (Laboratorio de Engenharia de Angola, Luanda, Angola).

CONTENTS

INTRODUCTION

Steady progress has been maintained in the development of the research programme, the principal aim of which is to obtain by means of field, pot, glasshouse and laboratory studies of soils and plants information of value in the maintenance and improvement of soil fertility. In this work the investigation of specifically Scottish problems is combined with basic research designed to contribute to agricultural progress in general. Co-operative work with other research organizations and with the agricultural advisory services has continued, and valuable scientific contacts have been strengthened by Institute representation at conferences and meetings bearing on its research activities, by the provision of facilities for visiting workers from both home and abroad, and by an increasing exchange of publications.

During the first week of June the Executive Committee of the International Peat Society held meetings at the Institute. Arrangements for the meeting, which was attended by representatives from Canada, Finland, Germany, Ireland, Norway and the U.S.S.R., were made by Mr R. A. Robertson, who is the British representative on the Committee.

Dr R. C. Mackenzie was granted two months' leave of absence from January to enable him to accept an invitation from the Senatus of the University of Cairo to visit Soil Science Departments of Universities in Egypt, to give a series of lectures on clay mineralogy, to visit centres where soil reclamation was in progress and to confer on problems of soil research.

Dr R. L. Mitchell accepted an invitation from the Organizing Committee of the XIII Colloquim Spectroscopicum Internationale to present a paper to a Geochemical Session of the Colloquium in Ottawa.

Dr V. C. Farmer was invited by the Clay Minerals Society of America, through a National Science Foundation Grant, to be guest speaker at a Conference on Clay Minerals which was held in Pittsburgh in October 1966. He presented a paper in the field of infrared absorption spectrometry applied to clay minerals. Following the conference, visits were made to Pennsylvania State University, Michigan State University and G.E.C. Schenectady. During the year Dr Farmer was also guest speaker at a meeting held in Paris which was organized by the Groupe Français des Argiles.

Mr R. A. Robertson attended and represented the Institute at a German-Polish Peat Symposium in April, organized by the Brenstofftechnische Gesellschaft in Kühlungsborn, near Rostock.

Following an invitation from the State University, Washington, U.S.A., Dr A. E. S. Macklon was granted leave of absence for one year from October, 1966 to enable him to work with Professor Higinbotham, as a Research Associate in the Department of Botany, on an investigation of the role of electrical phenomena in salt absorption by plant cells and tissues.

Dr M. V. Cheshire returned to the Institute in January on completion of the year's secondment which he spent with Professor Haworth on research on humic acid in the Department of Chemistry, University of Sheffield.

With the aid of grants kindly made available by the Agricultural Research Council, the Institute was represented as follows at various conferences

abroad: by Dr R. Glentworth at an F.A.O. Meeting on Soil Survey and Classification in Europe, held in Montpellier; by Dr I. R. MacDonald at a Meeting of the Society for Experimental Biology in Wageningen; by Dr V. C. Farmer and Mr W. A. Mitchell at a Meeting of the Clay Minerals Group in Brussels; by Dr A. M. Ure at the XIII Colloquium Spectroscopicum Internationale in Ottawa; by Dr R. L. Mitchell at the XIV Colloquium Spectroscopicum Internationale in Hungary; by Dr J. S. D. Bacon at the Seventh International Congress of Biochemistry in Tokyo; by Dr D. Vaughan at a *Humus et Planta* Symposium in Prague.

In addition to receiving a large number of short term visitors from twenty-one countries, the Institute has provided facilities for longer term work for visiting scientists from Angola, Argentine, Denmark, France, New Zealand, Spain, U.S.A., and Yugoslavia, as well as from centres in Great Britain.

Mrs Alison M. Innes, who has been a research student in the department of Plant Physiology since 1962, has been awarded the degree of Ph.D. of the University of Aberdeen. Theses submitted by two members of staff, Mr S. E. Durno, Pedology, and Mr N. M. Scott, Soil Fertility, in candidature for the degree of Ph.D. have also been sustained.

The announcement in the Birthday Honours List of the award of the M.B.E. to the Secretary of the Institute, Miss E. J. Dey, has given great satisfaction throughout the Institute.

Members of staff have again served on various technical committees appointed by such bodies as the Department of Agriculture and Fisheries for Scotland, the Ministry of Agriculture, Fisheries and Food, the Agricultural Research Council and the Forestry Commission, as well as on other scientific panels and groups.

PEDOLOGY

A better fundamental understanding of the complex soil system, from the viewpoint of its components, their properties, and how these interact to govern the properties of the soil as a whole, continues to be the objective of the work of the department. To this end progress has continued along the lines detailed in previous reports.

One of the interesting developments which has occurred over the past few years is how far the two main divisions of the department—dealing respectively with mineral and organic soils—are finding common ground. This is particularly the case with thermal methods which, although originally introduced for mineral studies, are finding increasing application to biological materials. Thus, not only can they give information on certain inorganic constituents of plant material[1,42] but they can also be used in investigation of the organic materials themselves—peat and the various components of plants and trees. Such studies have, however, a wider significance than is immediately apparent, since the information being collected will be of considerable value in the study of the compounds and complexes formed between the mineral and organic constituents of the soil. Little success can be expected in such a study, which is of undoubted relevance to plant-soil relationships, unless likely mineral and organic components are thoroughly characterized in advance.

Close collaboration with the Forestry Commission and the Hill Farming Research Organisation has continued, and several collaborative studies with other departments of the Institute have been pursued. Samples have been examined for the Forestry Commission, F.A.O., the Universities of Aberdeen, Rome and Cairo, Lincoln College (New Zealand), the Waite Institute (Australia), the Geological Survey of Israel, and Hunting Technical Services: such studies are valuable, not only in checking methods of investigation, but also in giving information on widely divergent samples, thus enabling results for Scottish soils to be put more clearly into perspective.

Several post-graduate workers have worked in the department for extended periods during the year. Mr A. S. Campbell, Department of Soil Science, Lincoln College, Canterbury, New Zealand, has assisted in the investigation of mixed inorganic gels in soil clays, and Mr J. A. Horta da Silva, Laboratorio de Engenheria de Angola, Luanda, Angola, is investigating the relationship of mineralogy to swelling and shrinkage of tropical soils. Mr S. S. Jørgensen, Department of Soils and Agricultural Chemistry, Royal Veterinary and Agricultural College, Copenhagen, Denmark, and Mr J. L. Perez Rodriquez, Centro de Edafologia y Biologia Vegetal, Seville, Spain, have just commenced periods of study. Dr A. S. de Endredy, F.A.O., Rome, has also assisted in the work of the department.

Dr R. C. Mackenzie was granted leave of absence to enable him to spend the months of February and March as Visiting Professor in the Soil Science Department of the Faculty of Agriculture, Cairo University, U.A.R. (Egypt). While there he delivered a course of lectures on advanced topics in clay mineralogy and in differential thermal analysis to post-graduate students of

Cairo and Ain Shams Universities (since collected into a volume[2] by Cairo University), advised students on research projects, visited research institutes connected with soils, and was fortunate to examine in the field soils of the major land reclamation sites in the U.A.R. He also delivered lectures at Alexandria University, Assiut University and the National Research Centre, Cairo. He is most grateful to Cairo University for their invitation and generosity, to the Minister of Irrigation, the General Desert Development Organization, the Organization for the Development of Reclaimed Land and many other bodies for their assistance with transport and accomodation, as well as to Professor M. Bakr, Dean of the Faculty of Agriculture, Cairo University, Professor M. Y. Shawarbi, Head of the Soil Science Department, Dr M. Naga, Associate Professor of Soil Mineralogy, and other individuals too numerous to mention for all they contributed to the success of the visit.

Members of staff have attended *inter alia* the seventh International Sedimentological Conference in Edinburgh, a meeting of project " Telma " of the International Biological Programme at Shrewsbury and Bangor, and two meetings in London, on the selection of standards for thermal analysis, under the auspices of the International Conference on Thermal Analysis, as well as meetings of the Particle Size Analysis Group and the Thermal Analysis Group of the Society for Analytical Chemistry. The department was also represented at the Agricultural Research Council Conference on Electron Microscopy at Babraham, Cambridge.

Mr W. A. Mitchell read a paper to a joint meeting of the Clay Minerals Group of the Mineralogical Society and the Groupe Belge des Argiles in Brussels. At the invitation of the Director of the Peat Institute, Rostock, Germany, Mr R. A. Robertson participated in a German-Polish Peat Symposium at Kühlungsborn, near Rostock, and, later in the year, at the invitation of the Ministry of Agriculture of Poland, in the anniversary meeting of the Polish Association for Land and Water Management. Mr H. G. Miller delivered a paper at the fourteenth Congress of the International Union of Forestry Research Organizations in Munich.

The Institute were hosts during the year to the International Peat Committee, of which Mr R. A. Robertson is a member. This Committee met to discuss arrangements for the third International Peat Congress to be held in Canada in 1968 and for the formation of an International Peat Society.

Mineralogical Methods

From a differential thermal study of benzoic acid sorbed on montmorillonite, it has been established that the complete combustion characteristics can be markedly affected by the diluent used, presumably through strong sorption from the liquid phase on to the surface of diluent particles. Of the three diluents tested—alumina, kaolinite and diatomite—the last mentioned proved to have the smallest disturbing effect [43].

A paper on the methods used for the mineralogical analysis of soils[3] has now appeared, and a review of instrumentation for differential thermal analysis, with particular reference to the factors involved in choice of suitable apparatus, has been prepared for a forthcoming book[44].

Pretreatment of Samples. Pretreatment of samples by ultrasonic waves, prior to chemical dissolution of non-crystalline inorganic constituents, has enabled the time of extraction to be markedly reduced, at least for clays separated from peaty podzol, peaty gley and humic gley soils; furthermore, no breakdown of crystalline clay minerals could be detected[45]. The method is therefore of considerable value.

Soil Mineralogy

Investigations on vertisols, reported last year, have been extended to include soils from the Sudan, Tanganyika and Ghana, with parent materials ranging in nature from basic igneous rocks to granite. All the soils are highly montmorillonitic and it would seem that surface cracking is associated with a high content of fine clay ($<0{\cdot}2\mu$) and the presence of exchangeable sodium.

A number of soils from the Luanda and Catete regions of Angola have been examined in order to assess whether any relationship exists between the swelling and shrinking characteristics of the soils and their mineralogical composition. The soils are derived from calcareous rocks and marls of Tertiary age. The presence of montmorillonite, kaolinite, illite, goethite, dolomite and calcite in these samples has been established by X-ray, thermal and electron-optical methods, and the investigation is continuing.

A number of soils from the U.A.R., India and Malaya have also been examined to determine how far the properties of these soils depend upon their clay mineralogy; a description of the mineralogy of some Turkish soils has now been published[4,5].

An account of the properties and mode of occurrence in soils of the various forms of silica has been submitted for publication[46], and a review of the characteristics under the electron microscope of finely particulate oxides of iron, aluminium and manganese has appeared[6].

Fine Sand Fraction. The separation and optical examination of the heavy and light fractions of the fine sand separates from soil samples taken by Soil Survey has continued. The same techniques are being used for the study of the sand-sized mineral grains in sedimentary and metamorphic rocks.

Clay Fraction. The systematic examination by X-ray diffraction and thermal methods of soil clays from the Banchory, Stonehaven and Forfar areas (Sheets 66/67/57) is almost complete. The usual suites of crystalline clay minerals have been observed, and again gibbsite has been noted as a common accessory mineral in clays from podzolic profiles developed on till derived from both acidic and basic igneous rocks. The largest amounts usually occur in the indurated B_3 horizon. In profiles where gibbsite is observed in samples from all horizons the A horizon is usually rich in aluminosilicate gel.

In order to obtain a better understanding of the non-crystalline components of soil clays, the $2\text{-}0{\cdot}2\mu$ and $<0{\cdot}2\mu$ fractions of highly allophanic soils from Japan and New Zealand have been intensively investigated by thermal and electron-optical methods supplemented by chemical and physical tests. The fine fraction, representing about 1-2 per cent of the total soil, is largely

responsible for the low-temperature hygroscopic moisture peak and for the height and sharpness of the high-temperature exothermic peak on the differential thermal curves. Variation in the amount and alignment of a fibrous component with pretreatment (particularly with the pH of the dispersing medium) was established by electron microscopy; where alignment of fibres was good a distinct electron diffraction pattern was observed. Specific surface areas of the coarse clay fractions were higher than anticipated, presumably because of channels within the particles.

A new apparatus has been constructed for the determination of specific surface areas. While still employing nitrogen adsorption, this operates at atmospheric pressure instead of under high vacuum. It is more convenient and rapid in operation and the results obtained are in very good agreement with those from the standard apparatus.

The value of a new technique, involving the replacement of active hydroxyl groups by the fluoride ion, in the study of natural inorganic gel material is being assessed. It has been applied to a series of samples, including clay minerals, Scottish soil clays, allophanic soils from New Zealand and Japan, and laboratory gel preparations, and results have been most promising. The values obtained for Scottish soil clays are very much reduced after treatment with dilute sodium carbonate solution, which removes the gel material, and indeed indicate that a less drastic treatment than that currently used may be effective in extracting the gel[45]. A study of the kinetics of the process of hydroxyl replacement by fluoride has commenced, and it is hoped that this test will indicate the activity of non-crystalline materials associated with particle surfaces. A paper dealing with the distribution of mixed silica-alumina-ferric oxide gels in some selected Scottish soils has now been published[7].

The study of the crystallization of alumina gels into bayerite, gibbsite and boehmite is being extended to cover the crystallization of mixed silica-alumina gels. Specific surface-area measurements are giving information complementary to that obtained by X-ray, optical, electron-optical and thermal methods.

Iron oxides in soil clays from Ghana have been shown electronoptically to occur as discrete, small ($<0{\cdot}1\mu$) electron-dense particles of irregular outline. Electron diffraction studies show these to be mainly goethite; only for one sample were patterns indicating the predominance of hematite obtained.

Rock Weathering. Studies on the natural weathering of biotite[8,48] have been extended to cover the alteration of micas under laboratory conditions. It has been found that biotite can readily lose potassium and be converted to vermiculite; muscovite, however, is much more resistant, as might be expected from the greater stability of this mineral under natural conditions. The early stages of alteration of some other important rock-forming minerals (olivine, amphibole, pyroxene and felspars) are also being investigated, using intermittent leaching with pure water at 45°C. The ions liberated are removed from the recycled water by exchange resins and the course of alteration is being followed by examining surface replicas under the electron microscope. A rusty coating which appeared on olivine has been found by electron diffraction to consist of goethite.

Manganese Minerals. In collaboration with Spectrochemistry, samples of lithiophorite and cryptomelane, separated from rock samples from a dususued mine near Tomintoul, have been examined for major and trace elements. These manganese minerals are common in soils, and lithiophorite, in particular, may contain considerable amounts of cobalt. Differences in trace element content can be related to differences in the crystal structure of the two minerals.

Mineralogy of Scottish Sedimentary and Metamorphic Rocks. From a study of the fine fraction separated from Dalradian limestones of the Moray Firth coast area it is concluded that the saponite present originated during the metamorphism of the limestones[49]. A mineralogical examination by X-ray and electron diffraction of phosphate-rich rocks from various localities in Scotland has shown that most contain apatite, although gorceixite has been identified in the clay fraction of one sample. The particle size of this mineral, according to electronoptical results, was about 0·1μ.

Organic and Biological Materials

In view of the results obtained during characterization of a Scottish peat profile by thermal methods[9], the effects of degree of humification and particle size on the differential thermal curve are being investigated in greater detail.

Collaboration in electron microscope studies with Microbiology and Plant Physiology has continued. A note on a new method for location of biological materials in the embedding medium prior to cutting by the ultramicrotome[10] and a paper on the lytic action of *Cytophaga johnsonii* on a eubacterium and on yeast[11] have been published.

Soil Analysis

Standard analytical determinations have been completed on soils collected by Soil Survey during the 1965 and 1966 field seasons and work on the samples collected during 1967 is now in hand. Clay separates from 110 soils have been analysed for silica, iron and aluminium and about 100 miscellaneous samples of soil, water, etc., have been analysed for other departments of the Institute and various outside bodies. Collaborative work with Soil Survey on the ability of aqueous extracts of pine needles to complex with sesquioxides continues. A preliminary statistical evaluation, by means of a computer, of field and laboratory information for three Scottish soil series has been carried out in collaboration with Soil Survey and Statistics.

Peat and Highly Organic Soils

The survey of selected peat deposits in the Stirling area (Sheet 29) is now almost complete. At the request of the Highlands and Islands Development Board two large deposits of peat in Ardnamurchan (Kentra Moss and Claish Moss) have been surveyed. In this survey aerial photographs were extensively used to correct detail on the old " County Series " 6-inch maps, which are the only large-scale maps available for the area.

Studies on the moisture-retention characteristics of peat have progressed, and, in particular, various horticultural types and gradings have been compared. It appears that, although there is a considerable variation in

moisture content at the lower end of the pF scale, at pF 4·2 (the wilting point) most values fall within the range 90-105 per cent, expressed on an oven-dry basis.

Laboratory investigations on peat, herbage and water samples have continued as in previous years. Numerous enquiries have been received and answered regarding the location and nature of Scottish peat resources and the methods of winning peat for horticulture, etc.

Hydrological Studies. The joint investigation with the Hill Farming Research Organisation on an experimental peat catchment at Blacklaw Moss, Lanarkshire, has been concluded and processing and analysis of the hydrological results are now in progress. In the spring of 1967 four of the seven micro-catchments were burnt over and this resulted in a significant increase in the conductivity of the run-off water. Work is now in hand to determine the nature and quantity of the nutrients involved.

Pollen Analysis and Quaternary Research. Systematic sampling and pollen analysis of deep peat profiles have continued along the lines, and with the objectives, previously reported. Samples have now been taken over a sufficiently wide area to enable the establishment of broad regional variations in the post-glacial history of Scottish vegetation. A thesis on Scottish woodland history since Boreal times as revealed by pollen analysis of peat, submitted by Mr S. E. Durno to the University of Aberdeen in candidature for the degree of Ph.D., has been sustained. Collaborative work with other departments of the Institute, with the Department of Geography, University of Aberdeen, and with individuals engaged on quaternary and prehistoric studies has increased. Samples have been taken from blanket bog profiles in the Acharacle and Kentra districts of north Argyll and in the Island of Jura. In Jura other sites were also investigated, including some of archaeological interest from which evidence of prehistoric settlement is expected to emerge. Pollen analysis is also in progress on samples submitted by Soil Survey from Drumuir Channel, Banffshire.

Studies on Forest Soils

In the drainage experiments on peat at Lon Mor, Inverness-shire (Ann. Rep. No. 36, 1965/66), the five plots are isolated by perimeter ditches in which the water level is maintained at levels of 0, 10, 20, 30 and 50 cm below the surface. One third of each plot is planted with *Pinus contorta*, the growth of which has been markedly affected by the treatments. After five years, the trees on the most deeply drained plot have attained an average height of 0·9 m, as against 0·3 m in the undrained plot—in which very few trees now survive. Samples of peat and needles are taken at frequent intervals for moisture determination and chemical analysis, respectively. Water-table heights and temperatures in the peat are also recorded regularly and, more recently, redox potentials in the peat have been measured. As regards moisture content, no striking difference has been observed either between the plots or between planted and unplanted areas within one plot below the top 10 cm. However, redox potentials have shown a wide distribution

between sampling points in the undrained plot and a much narrower, more normal distribution in the others. There is no clear correlation between redox potential and depth in any one profile, but the mean value is higher in the more deeply drained plots.

Tree Nutrition. The experiments on the nitrogen nutrition of coniferous trees, carried out in collaboration with the Forestry Commission, have continued. In an experiment initiated in 1964 at Culbin Forest, Morayshire, the effects of applied nitrogen fertilizer on the movement and distribution of nutrients within a nitrogen-deficient stand of Corsican pine is being investigated. Prior to the application of fertilizer a whole-tree sampling was carried out in this stand and, in addition, samples were taken of the ground vegetation, soil and forest floor. Detailed tests have now been carried out, in conjunction with the section of Statistics, to compare different means of converting sample-tree data to a per-area-of-crop basis. The results vary considerably between the different methods considered and it was found that the most satisfactory approach is to derive regression formulae for weight or nutrient content of tree components against some expression of tree size, such as basal area, and then to apply these to every tree in the crop.

Following the initial sampling, this crop was treated with four levels of nitrogen fertilizer for a period of three years, over which time the heaviest treatment amounted to 1350 lb nitrogen per acre. During the same period litter-fall and rainfall have been collected and analysed at regular intervals. The nitrogen applications were found to result in an increase in needle retention by the trees, following which there was a gradual rise in the weight of litter falling per unit acre. This was in part due to an increase in the weight of the individual needles falling[12]. As a result of the fertilizer treatments, the nitrogen concentration in the needle litter was more than doubled and hence the weight of nitrogen brought down in the treated plots rapidly exceeded that in the control. The fertilizer, however, was found to have little effect on the concentrations of phosphorus, potassium, calcium and magnesium and the quantities of these falling simply reflected changes in the weight of litter-fall. Comparison of the values obtained for the litter-fall in the control plots with the weight and nutrient content of the existing forest floor indicated that there must have been a progressive decline in the weight of litter falling since the onset of nitrogen deficiency and that the relative rate of release of nutrients from the forest floor has been slowest for nitrogen and most rapid for calcium. Following the three-year period of fertilizer application, a further complete sampling of the ecosystem has now been carried out in each treatment in order to assess the changes in the content and distribution of nutrients which were induced by the fertilizer treatment and the fate of the nitrogen so applied. Experience gained earlier enabled the sampling techniques to be improved, so that greater accuracy and increased speed were obtained.

In the same forest young leaves from heavily nitrogen-fertilized trees have developed necrosis of the leading bud suggesting a secondary deficiency of either copper or boron. In a preliminary greenhouse experiment, boron

deficiency has been induced in Corsican pine seedlings grown in sand taken from the affected area of the forest, but field experiments involving applications of boron, copper and zinc have as yet been inconclusive, since no bud deaths occurred during the past year, even in the plots which did not receive these elements.

Other fertilizer experiments have continued, and preliminary results from that involving nitrogen and phosphorus applications to 80-year-old Scots pine at Alltcailleach Forest, Aberdeenshire, were used in a recent paper by Binns and Grayson (*Scot. For.*, 1967, **21**, 81-98) to assess the economic implications of fertilization of established crops. Assuming the stand were felled about six years after treatment, they estimated the net discounted revenue resulting from fertilizing this crop to be of the order of £4 per acre, which represents a return of 11 per cent on the capital invested in the operation. This illustrates the returns that might result should a satisfactory means of forecasting the fertilizer requirements of different tree crops be devised.

The advisory service providing recommended fertilizer rates for forest nurseries, based on soil analyses carried out by Soil Fertility, has continued with little change.

Physical Chemistry of Forest Soils

The development of physical methods to characterize the state of aeration of peat has continued. In the peat-drainage experiment at Lon Mor, Inverness-shire, a method of measuring the rate of oxygen diffusion to a platinum microelectrode has been investigated, but the current-voltage characteristics of this electrode change with increasing hydrogen-ion concentration. Thus, in peat which has a relatively high concentration of hydrogen ions, the voltage range at which oxygen alone diffuses to the electrode is considerably smaller than that for mineral soils. Further preliminary experiments are therefore necessary before this technique can be applied with confidence in the field.

Laboratory investigations are being conducted into the physico-chemical factors that influence the availability of nutrient elements necessary for tree growth on peat. Suitable methods have been developed to determine the cation-exchange capacity and the degree of base saturation of raw peat samples. These involve the use of a continuous potentiometric titration technique to determine the hydrogen-ion concentration in acid-washed and raw peat. These studies are a useful precursor to investigations on preferential adsorption of cations and possible mechanisms of anion adsorption.

SOIL SURVEY

Systematic soil survey on a scale of 2.5 inches to 1 mile has continued. In the period April-September, 1967, approximately 285 square miles have been surveyed: 40 on Sheet 114 (Tongue), 40 on Sheet 110 (Latheron); 15 on Sheet 84 (Nairn), 35 on Sheet 83 (Alness); 50 on Sheets 43 and 44 (Iona, Mull); 15 on Sheets 40 and 41 (Kinross, Elie/N. Berwick); 10 on Sheet 32 (Edinburgh); 80 on Sheets 1, 2, 3 and 4 (Kirkmaiden, Whithorn, Stranraer and Wigtown). In addition extensive reconnaissance has been carried out on Sheets 43, 44, 51 and 52 (Island of Mull), and review and revision on Sheet 24 (Peebles). The late delivery of new vehicles limited appreciably the area surveyed in the early part of the season.

Two hundred and sixty-nine soil profiles have been sampled for analysis, including 40 sampled with the aid of the Proline Corer.

Progress has been made with the development of a Land Use Capability Classification based on soil mapping unit characteristics and a joint report with the Soil Survey of England and Wales has been prepared for submission to the Soil Survey Board. Land use capability maps have been prepared, at the request of various public bodies, covering 50 square miles on the Ross of Mull and 65 in the Inner Moray Firth on the scale of 1:25,000, and 100 square miles in the hinterland of Dundee and 400 square miles in the Western Borders area on a scale of 1 inch to 1 mile.

Mr J. I. Jack resigned on 30th September, 1966; Mr D. L. Dent was appointed to the staff, commencing on 1st November, 1966. Dr R. Glentworth attended the Sixth Session of the Working Party on Soil Classification and Survey of the F.A.O. European Commission on Agriculture in Montpellier, France, when it was proposed to prepare a soil map of Europe on a scale of 1:1 million following the experience gained in the publication in 1966 of a soil map of Europe on a scale of 1:2·5 million.

One surveyor spent three weeks with the Soil Survey of England and Wales at their Reading centre. Seven surveyors attended the spring Meeting of the British Society of Soil Science in London, where Mr J. W. Muir presented a paper on soil classification, and four attended the Autumn Meeting at Bristol.

Maps and Memoirs

Soil maps on combined Sheets 33, 34 and part 41 (Haddington, Eyemouth and part N. Berwick), 66/67 (Banchory/Stonehaven) and Sheet 14 (Ayr) have been published. First colour proofs of Sheets 7/8 (Girvan/Carrick), Sheet 39 (Stirling) and Sheets 48/49 (Perth/Arbroath) are awaited.

The memoir to accompany the Haddington/Eyemouth map is in press[50]. Drafts of the memoirs for Sheets 7/8 (Girvan/Carrick) and the parts of Sheets 83, 84, 93 and 94 covering the Black Isle have been completed. Memoirs are in preparation for Sheets 66/67 and 57 (Banchory/Stonehaven and Forfar), Sheet 14 (Ayr), Sheets 48/49 (Perth/Arbroath) and Sheet 39 (Stirling).

The Cartographic section has produced 6 inch to 1 mile soil maps of Whim Estate, Peeblesshire, and Milton of Cambus Farm, Perthshire, 2.5 inch to 1 mile soil and land use capability maps of the Invergordon area and the Ross

of Mull, a 2.5 inch to 1 mile land use capability map of the Alness-Dingwall-Beauly area and 1 inch to 1 mile land use capability maps of the Dundee hinterland and the Western Borders. Maps covering the relevant areas are produced by reprographic processes and hand coloured.

An account of the soils of the Dundee district has been prepared for inclusion in the handbook on the Dundee area for the forthcoming meeting of the British Association for the Advancement of Science.

At the request of the Highlands and Islands Development Board, Dr Glentworth attended a meeting in Inverness of persons concerned with land use. Subsequently a description of the soil and land use capability of the Invergordon area was submitted to the organizations concerned with the development of the area.

A report on his visit to New Zealand has been prepared by Mr J. M. Ragg.

A paper on land use capability has been written for *Reclamation*, an occasional publication of the Scottish Peat and Land Development Association[52].

Micro-morphological Studies

A further 260 soil thin sections have been made, and a considerable number of undisturbed soil samples have been collected for impregnation during the winter months.

The Thin-section Laboratory has been reorganized following the provision of an extra room for micro-morphological work. A Cutrock GH3 Cutting and Grinding Machine has now been installed.

Ad Hoc Work

Liaison has been maintained with the three Colleges of Agriculture, the Department of Agriculture and Fisheries for Scotland Inspectorate and Lands Branch, the Forestry Commission, the Institute of Geological Sciences, and the Highlands and Islands Development Board; also with various departments of the Macaulay Institute and several local authorities. Excursions and field demonstrations have been arranged and conducted in Morayshire, Stirlingshire, Ayrshire and the Lothians for various parties from these organizations and for the Edinburgh Soils Discussion Group. Arrangements were made for the visit of Professor van Baren and a party of fourteen students from the University of Utrecht, who were led on a one week tour of Scottish soils and landscape.

Talks were given to students from the Edinburgh School of Agriculture, the North of Scotland College of Agriculture, the Universities of Aberdeen and Edinburgh, to members of the staff of the Department of Agriculture and Fisheries for Scotland, and to a visiting party from the seventh International Sedimentological Congress.

A soil map was prepared and assistance given in arrangements for a Scottish National Drainage Demonstration at Milton of Cambus, Doune, Perthshire, arranged by the Stirling branch of the Department of Agriculture and Fisheries for Scotland and attended by some 3000 people.

A 6 inch to 1 mile survey of Novar Estate, Evanton, Ross-shire, has been started. A short report on the restoration of two open-cast coal-mining sites in Midlothian has been prepared for the Department of Agriculture and Fisheries for Scotland. An account of the soils of Upper Strathdon, Aberdeenshire, covering Glenbuchat Estate, has been written for publication as a bulletin, together with a soil map on a scale of 2·5 inches to 1 mile.

SHEET 84 (Nairn)

The area is situated along the southern shores of the Moray Firth. Covering 380 square miles, the region comprises the county of Nairn and parts of the counties of Inverness and Moray. The northern boundary is the shoreline between Inverness and Findhorn, whilst a line between Tomatin and Grantown-on-Spey forms the southern l'mit. Included in the survey were 13 square miles along the south east corner of the adjoining Sheet 94, comprising the Culbin Sands. The 18 square miles of Sheet 84 situated in Ross-shire around Rosemarkie and Avoch have been described in the Black Isle report. Agriculture and forestry are the main industries.

Relief is sharply divided into coastal lowlands, a highland area consisting of a "1000 foot" peneplain and a 2000 foot dissected plateau. These three contrasting landscapes reflect the influence and nature of the underlying solid rocks. The coastal belt is underlain by Upper and Middle Old Red Sandstone rocks, whereas the Highland area has been formed from the Moine Assemblage of Pre-Cambrian rocks together with various granitic intrusions. Contrast between these two regions is also heightened by the grain of the Moine strata running approximately south west to north east while the beds of the Old Red Sandstone lie parallel to the coast.

While the landscape has been determined mainly by the solid geology, it has been considerably altered by geomorphological agencies. For example, the "1000 foot" peneplain which has been established gently undulates between 750 and 1300 feet. The highly complicated glaciation of the area has also resulted in extensive changes to the topography. During the maximum glaciation of the Würm period ice emanated radially from the main distribution centre on the Moor of Rannoch. The northerly component of this ice was apparently confluent with ice flowing eastwards across the area from a centre in the Northern Highlands. Ice radiating from the Cairngorms must similarly have reinforced the main ice stream. The possible presence of Scandinavian ice in the Moray Firth has also to be considered.

The net result of this major glaciation has been the scouring and denudation of the 2000 foot dissected plateau and the deposition of a thick mantle of till over the peneplain. These deposits are 100 feet deep in places and have a blanketing effect on the topography. The complexity of this depositional history is evidenced by the occurrence of a schist till (40 feet thick) overlying a sandstone till (40 feet thick) at the edge of the peneplain.

During the melt-out stage of end-glacial times vast spreads of fluvioglacial sands and gravels were deposited over the peneplain and across the coastal lowlands. Kame-like ridges and mounds are especially well formed around Lochindorb where the Spey and Findhorn glaciers are believed to have

coalesced. Following deglaciation, differential movements of sea and land resulted in the production of four distinct beach levels at 15, 25, 50 and " 100 " feet. The immediate post-emergence stages of these beaches were of a lagoonal nature and pockets of sandy alluvium frequently overlie the fluvio-glacial silts and clays in depressed sites, for example at Dalcross. Post-glacial activity has thus tended to smooth the lowlands and produce wide raised beaches parallel to the coast. The combination of these easily eroded deposits and the prevailing east-west direction of the tidal current has led also to the concurrent processes of erosion and deposition, much of the Carses of Delnies and Ardersier being of recent origin. Due to the low rainfall, 25 inches, and the light texture of these coastal soils, wind erosion is a major soil forming factor. The Maviston and Culbin Sands, covering 14 square miles, are the end result of the offshore transport of sand in a westerly direction and its easterly return by wind.

Five major landform units may be recognized, namely:

1. Lowest raised beach (15 feet),
2. Higher raised beaches (25, 50, and " 100 " feet)
3. Drumossie Muir and the peneplain fringe
4. The " 1000 foot " peneplain
5. The 2000 foot dissected plateau.

Climate

A low rainfall, c. 25 inches, and a low diurnal temperature range of c. 5·5°C are the main climatic characteristics of the coastal lowland. At Nairn the mean annual temperature is 8·6°C and the mean temperature range (the difference between the average temperature of the warmest and coolest months) is 9·4°C. The rainfall is generally higher in the second half of the year, April to June being the driest quarter. Since the prevailing south westerly wind loses most of its moisture before reaching the Moray Firth, drought is a danger during spring and early summer.

The " 1000 foot " peneplain and the 2000 foot plateau, due to their exposed situation and increased altitude, have a relatively more severe climate. The 35 inch isohyet corresponds roughly with the edge of the peneplain and rainfall increases to reach a maximum of c. 50 inches on the 2000 feet summits. At Grantown the average annual temperature is nearly 1·4°C lower than at Nairn and night temperatures are from 2° to 4° lower than those on the coast.

Geology

Upper and Middle Old Red Sandstone strata underlie the coastal lowlands and metamorphic rocks of the Moine Series underlie the peneplain and plateau. The schists and gneisses of the Moine Assemblage are regarded as altered arenaceous and argillaceous members of an original sedimentary series. Although much of the area has been mapped as undifferentiated schists and gneisses, some of the metamorphosed argillaceous rocks have been identified as pelitic gneiss and schist. The normal type is a coarse flaky gneiss, often containing garnets, with large plates of muscovite and biotite. Due to differences in the original arenaceous sedimentary rocks a

wide variety of metamorphics are found, ranging from quartz granulites, quartzites, quartz schists, biotite granulites to granulitic biotite gneisses. Further complexities have been caused by both the pelitic and psammitic country rocks having been invaded by and impregnated with granite material which has resulted in the production of either an intrusion complex of igneous and metamorphic rocks or of synthetic gneisses. It is almost impossible to differentiate and map soils derived from these two major divisions with their numerous variants. All such soils have therefore been grouped in the Strichen Association.

Following upon the folding and foliation of the Moine Assemblage the rocks were invaded by granite masses in four major areas at Lethen Bar (2 square miles), Moy (28 square miles), Ardclach (30 square miles) and Craig Liath (3 square miles). The Moy granite is mainly a coarse-grained red biotite granite and closely resembles the pink muscovite granite of the Ardclach intrusion. The Lethen Bar granite, characterized by large felspar phenocrysts, is of a similar nature. At Craig Liath the granite is medium to fine-grained with white or pinkish felspar and has later intrusions of a more acid pink fine-grained rock. This granite also contains inclusions up to half a mile long of the surrounding pelitic schists. Despite their considerable area the major intrusions at Moy and Ardclach are of little importance in soil formation, being largely covered respectively by hill peat and fluvioglacial gravels. Where granite forms the parent material, the soils have been mapped within the Countesswells Association.

Between Inverness and Nairn the coastal lowlands are underlain by rocks of the Middle Division of the Old Red Sandstone which rest unconformably on the Moine schists. The general succession begins with a basal conglomerate followed by shales with fish-bearing beds and overlain by sandstones and flags. Only the conglomerate and arenaceous sandstones are important, producing respectively the Kessock and Cromarty Associations. From Nairn to Forres the Middle Old Red Sandstone is covered disconformably or uncomformably by the Upper Division of the formation. These coarse false-bedded yellow and reddish grey sandstones give rise to soils of the Elgin Association.

Soils

Podzolization, induration and light textures characterize the soils of Sheet 84. The common occurrence of an iron pan or indurated layer or both gives rise to a typical bisequal drainage regime. True gleys are therefore scarce and generally occur only in concave flush sites on hillsides. Peaty podzols, iron-humus podzols, humus podzols and peaty gleys with induration are the dominant genetic soil groups. Except for the sandy clay loams of isolated colluvial gleys, the texture is seldom finer than sandy loam.

Unlike the iron podzol described as the modal podzol profile over much of north east Scotland, with a grey A_2 horizon overlying a strong brown B_2 horizon, the podzolic profile in this area has a well defined organo-mineral layer between these two horizons. Varying between 1 and 3 inches thick, it shows a marked increase in loss of ignition values and correlated percentage

organic matter as compared with the A_2 horizon values. Selected percentage loss on ignition values are

	A_2	A/B or B_1	B_2
Dorback	4.14	9·38	4·77
Dunearn	2·96	12·00	8·33
Cawdor Burn	2·36	12·40	7·55
Whinhill	4·80	17·80	11·20
Dava	4·56	10·50	8·24
Tuttach	3·33	9·34	5·98

Dark reddish brown (5YR3/2) in colour, this A/B or B_1 horizon contrasts with the usual dark grey (5YR3/1) or brown (7·5YR5/2) coloration of the A_2 horizon and the strong brown colour (7·5YR5/6) of the B_2 horizon. Frequently the upper part of the latter horizon is of stronger colour, namely, yellowish red (5YR4/6). These profiles have been identified as iron-humus podzols.

Since the soils of the region are derived mainly from arenaceous sandstone, schists and granites, they are inherently low in exchangeable cations. In addition their nutrient reserve has been considerably depleted by strong leaching. Exchangeable calcium is always extremely low below the A horizon of the natural peaty podzol and iron-humus podzol. The sharp decrease of calcium values in the B horizon with a slight rise or decrease in the C horizon as reported in the podzolic zone in Aberdeenshire is found only in the cultivated iron-humus and humus podzols of the coastal lowlands. Conversely, exchangeable magnesium is always present, though often in minute quantities, thus reversing the trend in arable soils where magnesium values are normally one-fifth to one-tenth the calcium value.

In the brown podzolic soils formed on the fluvioglacial gravels of the long-established deciduous woods of Cawdor and Darnaway there is a similar tendency for calcium to be low below the A horizon and for magnesium to be present throughout the profile. The calcium values for the H/A horizons are considerably less than those of the peaty podzols and iron-humus podzols, due to the lower percentage organic matter and possibly in part to the greater abstraction by the nutrient cycle of deciduous trees.

Lowest Raised Beach

The lowest raised beach comprises the Carses of Ardersier and Delnies and the shores of Findhorn Bay. It consists of excessively drained partially or wholly stabilized micro-dunes and very poorly drained flats. The soils are immature with an AC profile, the latter horizon formed exclusively in sand. In the very poorly drained areas the A horizon is wholly organic and relatively shallow, ranging in depth from 3 to 8 inches. Extremely high values for exchangeable cations reflect the dominating influence of tidal salt water; maximum figures recorded were:

Calcium	15·0 me/100 g
Magnesium	23·9 me/100 g
Sodium	59·6 me/100 g
Potassium	4·0 me/100 g

In these saline gleys a permanent water table is encountered at c. 15 inches, where the intensity of the anaerobic reducing conditions is indicated by the typical grey coloration 5YR5/1. Associated with this water-logging are extremely acid conditions, pH values varying between 3·5 and 4·5.

The sand dune areas are prone to wind erosion. A consequence of their long instability is the common occurrence of weakly developed A horizons which are seldom more than an inch thick and are sandwiched between layers of aeolian sand. Apart from variations within the A horizons, a remarkable feature of both wet beach and dry sand dunes is the constancy of particle size distribution. Though the average sand content of the C horizon ranges from 96·1 to 97·4 per cent, thirteen samples from a total of thirty collected from seven profiles had a sand content of 96·8 per cent. Clay ($<2\mu$) values range from 2·9 to 4 per cent and silt ($50\text{-}2\mu$) from 0·0 to 1·1 per cent.

Higher Raised Beaches

Fluvioglacial sand and gravels of the Boyndie and Corby Associations form the dominant parent materials of the higher raised beaches. These deposits vary enormously in depth, ranging from 2 to 3 feet at Ardersier and Connage to more than 319 feet recorded in a bore at Inverness. Occasionally a sandy loam till of the Elgin Association derived from the underlying Old Red Sandstone forms the C horizon. Around Inshock and Hardmuir the profile is wholly developed on such a till. In other localized areas, for example, Poolton, Allanfearn and Dalcross, the parent materials are respectively peat, fluvioglacial silts and clays and recent sandy alluvium. Outwith the kettle-hole and kame-like gravel complexes at Alturlie, Blackcastle and Flemington the remaining areas of soils developed on gravel are limited in extent, with the gravel usually forming a capping some 3 to 6 feet thick overlying the sand.

A distinctive feature of many of these coastal soils is an exceptionally deep A horizon, sometimes as much as 20 to 30 inches deep, which has been recorded over the whole range of C horizon materials. The physical composition of these A horizons is remarkably uniform, with clay 10 ± 2 per cent and silt 25 ± 5 per cent. These values are consistently higher than those found in normal topsoils.

Around Castle Stuart occurs a fluvioglacial sand with a relatively high silt fraction of 20 to 30 per cent throughout the profile. The clay fraction, which is highest in the A horizon, c. 8 to 12 per cent, drops by 50 per cent in the B horizon and reaches a minimum in the C horizon, c. 1·5 to 4 per cent. Texturally the whole profile to a depth of 6 feet is a sandy loam. Classified as a humus podzol and named the Ardersier series, this soil has been assigned to the Boyndie Association. Both B and C horizons are distinctly current-bedded and soft iron/humus bands approximately $\frac{1}{4}$ inch thick (the definitive orterde horizons) are prominent in the B_3 and C horizons.

The typical Boyndie profile is characterized by a very high sand content of 90 to 95 per cent in both the B and C horizons. Clay and silt values steadily decrease downwards to 0·2 per cent and 0·7 per cent in the C horizon.

A group of poorly drained soils represent the most recently formed soils on these higher raised beaches. Alluvium of a sandy or silty fine sand texture

forms the parent material. Occasionally peat, which may be underlain by thin marl beds, overlies the alluvium. A permanent water table is found between 30 and 40 inches from the surface and prominent iron mottles, especially in the form of iron tubes around old root channels, are common in the upper part of the profile.

Exchangeable calcium values in these mineral surface horizons are higher at 12 to 14 me/100 g than the values for the freely drained soils elsewhere on the raised beaches. This is probably associated with the higher percentage of organic matter, that is, 9 per cent as compared with 5 to 6 per cent, and the tendency for these sites to be maintained as permanent pastures. Exceptionally high calcium values, for example, 92 me/100 g, are found in the marl bands. The highest recorded pH values, 7·5, in the whole Sheet area were obtained from these deposits. Conversely, the most strongly acid conditions encountered, namely pH 3·2, were recorded from the C horizon of these profiles.

The majority of the soils of the coastal lowlands are cultivated humus and iron-humus podzols, derived from sands and gravels with low clay organic matter and exchange capacities. Manurial practices complicate the chemical regime though the following trends may be observed.

Except for calcium and magnesium, which are normally present in medium values (3 to 8 me/100 g), the exchangeable cations in the A horizon have medium to low values. Calcium, magnesium and potassium usually show a sharp decrease in the B horizon and a very low minimum in the C horizon.

The C horizon values for magnesium, sodium and potassium range from $<0{\cdot}01$ to 0·09, with the majority of values $<0{\cdot}04$. Except for the clay and wet alluvial soils, pH conditions across the coastal belt are slightly acid, that is, pH 5·5 to 6·5. Values commonly increase slightly with depth. The total phosphorus content is at a maximum in the A horizon of all soils, with values ranging from slightly low to medium moderate. In sandy or gravelly soils the content decreases down the profile, with a minimum of low value in the C horizon. A minimum of low to medium value occurs in the B horizon of the soils derived from clay or silt and is followed by a slight rise in the C horizon. This trend is also observed in the poorly drained alluvial soils. Except in these latter soils, there is an abrupt rise in the C horizon for the values of acetic-acid soluble phosphorus—c. 15 to 20 mg P_2O_5/100 g. A low, occasionally moderate, minimal value is found in the B or lower part of the A horizon. In the poorly drained alluvial soils there is no trend and values in all horizons tend to be low, c. 4.

Drumossie Muir

Drumossie Muir is a low-lying ridge separating the Nairn valley from the coastal belt. It rises gradually in a south-west direction for eight miles from 150 feet above sea level around Tomluncart to a maximum height of 800 feet near Leys Castle. Sandstones of the Middle Old Red Sandstone underlie the whole ridge except for a small area of black flaggy shales outcropping near Leys Castle. Smoothness of slope and a regular configuration are distinctive features.

Intense induration and poor surface drainage conditions characterize the majority of the soils, giving rise to imperfectly drained peaty podzols and peaty gleys with induration. Although a stony sandy loam till of the Cromarty Association overlies the sandstone rock, the upper part of the profile is more commonly developed on an overlying mantle of the partially re-sorted till. These soils belong to the Kindeace Association. Along either flank of the Muir to a height of 300 feet are stretches covered by a veneer of moraine-like material derived from the water-sorted till. The soil varies from a gravelly loamy sand to a loamy sandy gravel and has been assigned to the Ardvanie Association, the sandstone counterpart of the Dulsie Association.

In the Kindeace Association a stony sandy loam texture is uniform throughout the profile. Clay is at a minimum of 9 per cent in the A horizon and increases downwards to a maximum in the C horizon of c. 14 per cent, whereas U.S. silt values display no trend, varying from 20 to 30 per cent in all horizons. Corresponding sand values range from 55 to 65 per cent, though occasionally in highly modified layers a maximum of 80 per cent may be reached.

The normal profile has a peaty horizon of 2 to 6 inches in depth overlying a black A horizon of structureless humose sandy loam. The B_2 horizon, if present, is variably gleyed and mottled, though more commonly there is simply a gleyed A/B horizon overlying an intensely indurated B_3 horizon. The latter has a strongly developed platy structure and is frequently delineated by a discrete iron pan an eighth to a quarter of an inch thick. The unmodified C horizon is moist, extremely firm and massive. Diffuse iron staining and tapering vertical cracks filled with a grey loamy fine sand are characteristic of this horizon. The drainage of these profiles is primarily determined by the presence of the impermeable indurated layer. Slight variations in the slope of the site may produce marked changes in the surface drainage conditions. Thus the C horizon is always slightly imperfectly drained, whereas the A and B horizons above induration range from imperfect to very poor.

In the Ardvanie Association clay content is at a maximum in the A horizon at c. 11 to 14 per cent, and decreases downwards to a minimum of 1·5 to 6 per cent in the C horizon. Silt values similarly decrease from 20 to 30 per cent in the A horizon to 10 to 20 per cent in the C horizon. Structure in the B horizon varies from weak sub-angular blocky to strongly developed platy. The C horizon is structureless, though traces of apparent bedding are common in occasional lenses of sand and silt. These soils are cultivated iron-humus podzols and are freely drained, becoming slightly imperfectly drained with depth.

Apart from medium values (3 to 8 me/100 g) for exchangeable calcium and occasionally for potassium in the A horizons of the cultivated soils, the values of the cations are low. These soils differ from the coastal sandy soils in that these cations are seldom $< 0{\cdot}01$ in any horizon. An exception is magnesium which is usually $< 0{\cdot}01$ in the B horizon of the peaty gley with induration.

In the freely drained morainic soils of the Ardvanie Association the calcium, magnesium and potassium values show a sharp decrease in the B horizon similar to that displayed by the coastal sandy soils. The decrease continues

to the C horizon where values of magnesium, sodium and potassium are of a similar very low order, ranging from 0·01 to 0·10 me/100 g, with the majority of values $< 0{\cdot}05$.

Except for calcium the downward trend of the exchangeable cations is not observed in the imperfectly and poorly drained till-derived soils. There is a tendency for the sodium and potassium values to rise slightly in the C horizon. Magnesium values also tend to rise in the C horizon after a minimum in the B horizon. Despite these minor trends and variations the C horizon values for magnesium, sodium and potassium are still extremely low, ranging from 0·03 to 0·20 me/100 g.

The total base exchange capacity of the morainic soils decreases with depth to a minimum of 2 to 4 me/100 g, mainly < 3 me/100 g. In the till-derived soils the range is similar, mainly 3 to 4 me/100 g.

As with the coastal soils the pH values of the cultivated soils are slightly acid. In uncultivated soils conditions are strongly acid in the surface, pH 4·0 to 4·3, and become moderately acid with depth, pH 4·7 to 5·2.

Total phosphorus shows a maximum of medium value, 110 to 207 mg P_2O_5/100 g, in the A horizon of the morainic soils followed by a marked decrease to a low value, 58 to 104 mg P_2O_5/100 g, in the B horizon. C horizon values may rise or fall slightly. In the till-derived soils a minimum of low value, 45 to 102 mg P_2O_5/100 g, is found in the A horizon and values increase with depth to medium, 123 to 155 mg P_2O_5/100 g, in the C horizon.

Usually in the uncultivated morainic soils the acetic-acid soluble phosphorus values show a minimum of low to medium value, 2·7 to 7·8 mg P_2O_5/100 g, in either the A or B horizons. There is an abrupt increase to high values in the C horizon. A minimum of very low value, 0·4 to 1·4 mg P_2O_5/100 g, is found in the A horizon of the uncultivated till-derived soils. The values increase with depth to very high values, namely, 60 mg P_2O_5/100 g, as opposed to the maximum value of c. 30 mg P_2O_5/100 g in the freely drained cultivated soils.

" *1000 foot* " *Peneplain*

Fluvioglacial sands, gravels, and gravelly loamy sands of the Boyndie, Corby and Dulsie Associations form the largest group of soils on the " 1000 foot " peneplain. These deposits range from the flat wide terraces of the River Findhorn to kame-like and eskerine complexes around Lochindorb where the well sorted gravels of the Corby Association frequently form a capping from 3 to 6 feet in depth overlying current-bedded sands. Rudely stratified gravelly loamy sands of the Dulsie Association are scattered across the peneplain in long low mounds and are occasionally capped by well sorted gravel. The soils of the Dulsie Association closely resemble those of the Corby Association, differing in degree of scoring and in topographic situation. Whereas the U.S. silt values for the B and C horizons of Corby soils are normally < 5 per cent, those for the Dulsie soils vary between 10 and 25 per cent. Clay values are < 5 per cent in the B and C horizons of both associations and may be < 2 per cent in the C horizon of the Corby Association.

On the steep kames occur typical peaty podzols and iron-humus podzols with strongly developed A_1, A_2, A/B, Fe pan and B_2 horizons. Despite the presence of an iron pan overlain by peat up to 10 inches thick there is little evidence of gleying in the A_2 horizon. Strongly gleyed A and A/B horizons are commonly found on flattish sites where the peat may be up to 15 inches in depth. The B_3 horizon is commonly indurated. Chemically the Dulsie and Corby Associations are similar. Due to their coarse texture, high porosity and low clay values, their exchange capacity is low, except in the H and A horizons. The peaty surface layer has a high percentage of organic matter, ranging from 61 to 100 per cent, with the majority of values >80 per cent, and a very high C/N ratio ranging from 26 to 47, with the majority >40. pH values of these acidic surface horizons are extremely low, namely, pH 3·8 to 4·4, but increase downwards to a C horizon range of pH 4·8 to 5·5. The total exchange capacity of the H horizon is high, 80 to 100 me/100 g, although the degree of saturation is low, ranging from 17 to 25 per cent. A marked decrease of the exchange capacity and exchangeable bases occurs in the mineral horizons, values for the C horizon being <2 me/100 g at a base saturation of <5 per cent. Calcium never exceeds 0·01 in the B and C horizons, whereas its value in the H horizon ranges from 2·45 to 17·38 me/100 g. Corresponding magnesium values are similarly high in the peaty horizon, ranging from 0·88 to 13·08 me/100 g, with the majority 6 ± 1 me/100 g. Potassium values range from 1·07 to 2·09 me/100 g in the H horizon, dropping to $<0{\cdot}10$ in the A horizon and decreasing steadily to the C horizon where potassium is frequently present in only trace amounts, c. 0·02 me/100 g or less. Sodium has similar values, though fluctuating within a wider range in the mineral horizons, namely 0·02 to 0·15 me/100 g. Total phosphorus, apart from a maximum in the H horizon of c. 130 mg P_2O_5/100 g, shows no trend in the mineral horizons where values range from 20 to 100 mg P_2O_5. Acetic-acid soluble phosphorus, however, displays a distinct maximum in the H horizon, c. 14 to 20 mg P_2O_5/100 g, followed by an abrupt decrease to <2 mg P_2O_5 in the mineral horizons. Occasionally the C_2 horizon of the Dulsie profile shows a secondary maximum.

2000 Foot Dissected Plateau

The Strichen Association and, to a lesser extent, the Countesswells Association are widespread across the flanks of the 2000 foot plateau and on isolated hills protruding above the peneplain. Derived from schists and granites respectively the parent materials are a stony sandy loam and a stony gritty sandy loam. A peaty podzol with iron pan is the dominant profile. Peaty gley soils are scarce and confined to concave colluvial sites on the foot-slopes.

On some very steep slopes, for example in the Streens area of the River Findhorn, freely drained colluvial or creep soils are characteristically revealed by terracette patterns. The profile consists of a moder/mull A horizon overlying a strong brown (7·5YR5/6) B_2 horizon. In these sites steepness of slope prevents the establishment of a vegetational mat and the accompanying development of a mor humus or peaty surface horizon as is found in immediate shallower slopes. Ill-advised burning of the vegetation has also

increased the tendency towards erosion. This profile has been reported elsewhere in Britain. These soils have been interpreted as truncated podzols or as " Creep Brown Earths " resulting from contemporary surface movement. Another view stated that " these sesquioxide rich Brown Earths may be simply the result of extreme soluviation with little cheluviation." Other areas of apparently podzolic soils with a Brown Earth A horizon are related to the widespread occurrence of cairn-fields. They commonly occur between 1000 and 1500 feet. Archaeologists have suggested that these sites combine burial grounds and land clearances of the Neolithic-Bronze Ages.

Both associations include a series formed on deeply weathered rock which is frequently encountered on the 2000 foot plateau. Occasionally a podzolic profile is formed directly in the weathered material, but more often there is a 2 foot mantle of till-like debris containing unweathered sub-rounded stones overlying the weathered rock. A highly weathered Old Red Sandstone conglomerate has also been recorded in which the matrix and constituent rocks, mainly biotite schists and granites, are so completely altered that they are easily dug out by hand.

Peaty podzols with or without an iron pan are the dominant soils of both the Strichen and Countesswells Association. In the Charr series of the Countesswells Association the total exchangeable cations are at a maximum in the organic surface horizon where the C/N ratios vary from 22·6 to 34·3, with an associated percentage of organic material varying from 78·91 to 92·84. Whereas exchangeable calcium and magnesium values are high in the H horizon at c. 11 and 6 me/100 g respectively, exchangeable calcium falls to $<0{\cdot}01$ in the mineral horizons. Magnesium values drop markedly in these horizons and generally decrease downwards within a range of 0·03 to 0·96 me/100 g. Sodium and potassium are present in minute quantities in the B and C horizons and no trends are discernible. The total exchange cation complex drops from 90 to 120 me/100 g with a base saturation of 10 to 20 per cent in the H horizon to extremely low values of <3 me/100 g in the C horizon. Base saturation is at a minimum of c. 5 to 10 per cent in the A and B horizons and rises slightly to 10 to 20 per cent in the C horizon. Total phosphorus, apart from a maximum in the H horizon of 80 to 230 mg P_2O_5/100 g and a marked minimum of 14 to 39 mg P_2O_5/100 g in the A_2 horizon, shows no trend in the B and C horizons where values fluctuate between 30 and 125 mg P_2O_5/100 g. Acetic-acid soluble phosphorus displays a similar maximum in the H horizon, ranging from 20 to 40 mg P_2O_5/100 g, but decreases markedly in the A horizons, ranging from 0·2 to 2·9 mg P_2O_5/100g.

The peaty podzol of the Strichen Association shows similar trends and values.

Peat

Within the area two types of peat have been mapped, namely:

1. Zonal peat < hill peat / shallow blanket peat
2. Azonal peat —— basin peat

Due to the combination of altitude, relatively high rainfall (c. 40 to 50 inches), marked seasonal variations in temperature, and periodic exposure to desiccating winds, peat has formed an extensive mantle from approximately 1500 to 2000 feet. This belt of climatic or hill peat increases in depth from c. 3 feet on the trailing slopes to an average of 6 to 8 feet on the summit of the 2000 foot plateau. Usually the individual peaks of this dissected plateau are free of peat, whereas in depressions and saddles the peat may increase in depth to c. 12 to 15 feet. A dendritic drainage pattern characterizes this area with the pattern becoming intense in local basins.

Although climatic conditions are still conducive to peat formation, erosion of the peat mantle is extensive with many of the drainage channels now cutting into the underlying mineral soils. In a few gently concave sites, for example, Carn An Daimh, this erosional cycle is almost complete. The isolated hags, produced by the down-cutting streams, are being reduced by desiccation and aeolian action to form a shallow layer of redistributed peat. The progressive removal of this water-absorbent mantle could lead to long term flood control problems at lower levels.

Azonal basin peats are widely distributed. Those situated on the raised beaches, for example, Poolton, are soligenous and are frequently underlain by marl deposits. They seldom exceed 6 feet in depth. Ombrogenous basin peats are typical of the 1000 foot peneplain and may attain a depth of 25 feet, for example, Dava. Though they may display micro-erosion depressions they do not possess the dendritic drainage pattern so characteristic of hill peat.

All mineral soils above 500 to 600 feet have a peaty surface horizon. In the initial memoir of the Scottish Soil Survey (Banff, Huntly, Turriff) peat was "generally considered to be over 15 inches deep," though in succeeding memoirs this depth has been reduced to 12 inches. To map all soils as peat when there is only 12 inches of organic material overlying mineral soils would be misleading in this area where depths of blanket peat are apparently correlated with altitude and slope. Since experience has shown that most of the shallow slopes on the peneplain and the steeper slopes within the 2000 foot dissected plateau are seldom covered by more than 15 inches of peat, excluding L and F layers, the lower limit of peat has been taken as 20 inches.

Most peats reveal a seam of pine tree stumps from 3 to 6 feet below the surface and in many sites two such grenzes are apparent. The roots are generally ovoid in section and distinctly buttressed. Trunks of 18 inches in diameter and up to 25 feet in length are occasionally found. The base of the peat is usually characterized by birch stems seldom more than 1 to 2 inches in diameter. Preliminary pollen analyses indicate that the 1000 foot peneplain peats are of Boreal age whereas the climatic peat is of Boreal-Atlantic transitional period.

The hill peat is strongly acid, with pH values ranging from 3·6 to 4·4. The dominating influence of the very weak and insoluble acids of the "true humus" within the peat is reflected by these acidic conditions and the high exchangeable hydrogen values which vary from 75 to 165 me/100 g.

Exchangeable calcium values in the top six inches range from 4·9 to 9·5 and generally decrease rapidly to very low values at around 30 inches. Contrary to the 10:1 or 5:1 ratios of calcium to magnesium in arable mineral soils, the magnesium values in peat are slightly higher than those for calcium in the top six inches and are usually two or three times the calcium values below that depth. Base saturation is obviously low, varying from 1 to 20 per cent. Acetic-acid soluble phosphorus ranges from 12 to 18 mg P_2O_5/100 g in the top six inches and decreases abruptly below 12 inches to a range of 2·2 to 0·0 mg P_2O_5/100 g. Values for total phosphorus, however, vary considerably, from 70 to 127 mg P_2O_5/100 g in the top six inches and from 23 to 143 mg P_2O_5/100 g below 12 inches. The C/N ratio is high, 25·1 to 59·7.

Agriculture

Agricultural systems reflect the two primary topographical divisions, with the coastal lowlands being devoted to arable farming and the peneplain to stock rearing. As a result of its low rainfall (25 inches) and a low diurnal temperature range of 12°F the coastal arable belt is ideally suited for cereal production. The area is particularly noted for barley. Wheat acreage in Nairnshire was 433 acres in 1960, and is unlikely to expand greatly in view of the dominating sandy loam-loamy sand soil textures. Oats are the main crop in the fringe area between the raised beaches and the peneplain. Potatoes and grass constitute the remaining important crops, with cattle fattening being traditional in the area. The change from fat cattle sold at 2 to 3 years old at 10 to 12 cwt to younger cattle sold at 14 to 24 months at around 7 to 10 cwt has resulted in an increase in the total numbers fattened annually. Over the last 50 years the cattle population in Nairnshire has risen from 6000 to 11,000.

Moray and Nairn are not as heavily stocked with sheep as the surrounding counties, partly because of the emphasis on cattle rearing in the sheltered valleys and the fact that the economy of the greater part of the peneplain is based on the rental of grouse moors. Where sheep are kept emphasis is mainly on feeding and wintering.

Following the national trend there has been a gradual reduction in the number of farms, correlated with an increase in size. In 1912 Nairnshire possessed 347 farms with an average acreage of 73·0, whereas in 1960 there were 262 farms of an average 93·9 acres.

Forestry

Forestry in Moray and Nairn has been long established, the private estates of Darnaway, Cawdor, Lethen and Seafield having pioneered afforestation techniques. Records of these private woodlands date from the 17th and 18th centuries though their maximum expansion was reached in the late 19th century. Approximately 20 per cent of Moray and Nairn is afforested, with the total acreage of 80,000 acres divided equally between private and state ownership. Some 24,000 acres of trees felled during the two World Wars have since been replanted and new planting is around 1000 acres per year. Further devastation was caused by the 1953 gale when ten million Hoppus feet of timber were blown down.

Changes in methods and the more extensive use of the lodgepole pine (*Pinus contorta*), Sitka spruce (*Picea sitchensis*) and Norway spruce (*Picea abies*) have pushed the inland exposure limit to c. 1500 feet and led to increased afforestation of the exposed and infertile moorland. The introduction of these species has largely been at the expense of the Scots pine (*Pinus sylvestris*) though the latter is still the dominant species, forming 66 per cent of trees planted. European larch (*Larix decidua*) is being largely replaced by Japanese larch (*Larix leptolepis*) and hybrid larch (*Larix eurolepis*).

The stabilization and afforestation of 7500 acres of aeolian sands at Mavis-ton and Culbin since 1927 has been a major forestry achievement. After thatching with branches and establishing marram grass to fix the sand, Corsican pine (*Pinus nigra* ssp. *calabrica*) was planted. The species was selected because of its ability to withstand salt winds and severe drought.

The acreage of hardwood trees is small at c. 4000 acres and consists mainly of oak and beech situated on brown podzolic soils on the coastal arable belt, for example, Cawdor Oak Wood. The tendency is to replace the trees on these more fertile sites with the faster growing species such as Douglas fir (*Pseudotsuga menziesii*).

SPECTROCHEMISTRY

In a laboratory concerned mainly with the serial determination of inorganic trace and major elements for the study of soil status and soil:plant relationship, a balance must be maintained between analytical continuity and introduction of new or improved techniques. It is inadvisable to introduce modifications into the analytical procedure unless some clear-cut long-term advantage is apparent. Minor changes should not be made piecemeal but at some specific stage, so that check can be kept of any effects arising from modified techniques. The policy in this department has been to retain established methods unmodified for as long a period as possible and not to introduce new methods until they were fully confirmed. This has been justified by experience. There are however major improvements and new techniques which give such marked advantages that it is essential to adopt them. These have included atomic absorption methods and similar fundamental new techniques, so that the tendency is always to widen the scope of the methods employed.

The application of computer assessment to the evaluation of readings obtained by variable internal standard arc spectrographic methods has been shown to be practicable, and it is hoped to introduce this procedure as soon as facilities become available on the computer being installed at the Rowett Research Institute. This should save some calculation time and reduce the necessity of checking to eliminate the occasional mathematical slips that inevitably occur in calculations. The advantage of computer calculation should be considerably greater after the large direct reader which is at present on order has been installed, as it is hoped to incorporate read-out on punched tape suitable for direct handling by computer. This should enable inter-element interference to be compensated for much more efficiently than is feasible at present. Preparations to facilitate this major change in the operation of the department have been made during the past year.

During the year Professor J. L. Ahlrichs, Department of Agronomy, Purdue University, Lafayette, Indiana, U.S.A., completed an eleven-month stay in the department, working on infrared problems, while Mr P. D. Jolodovsky, Laboratory of Spectroscopy, National Institute of Industrial Technology, Buenos Aires, Argentina, spent ten months studying emission techniques. Professor B. G. Ellis, Department of Soil Science, Michigan State University, East Lansing, Michigan, U.S.A., and Mrs C. Perez Rodriguez, Estacion Experimental del Zaidin, Granada, Spain, have commenced periods of work on trace element and spectrochemical problems respectively. Many overseas workers have been included amongst those who have visited the department for shorter periods to discuss various aspects of the work.

Dr R. L. Mitchell attended the XIII Colloquium Spectroscopicum Internationale in Ottawa, Canada (on the invitation of the Organizing Committee), and the XIV Colloquium in Debrecen, Hungary, and Dr A. M. Ure attended the XIII Colloquium. Dr V. C. Farmer was invited to be a guest speaker at a Conference on Clay Minerals in Pittsburgh in October, 1966. Following the conference Dr Farmer visited Pennsylvania State University, Michigan

State University and the General Electric Co. Laboratories in Schenectady, at all of which work on clay mineralogy is undertaken. Dr Farmer was also invited to present a paper to a meeting of the Groupe Français des Argiles in Paris and attended a joint meeting of the British and Belgium Clay Minerals Groups in Brussels and Louvain. Members of staff took part in various scientific and technical meetings during the year.

Trace Elements in Soils, Plants and Biological Materials

Considerable progress has been made in the long-term investigations of trace element behaviour in soils and soil:plant relationships, as well as of seasonal and positional variations within the plants. These studies, involving the determination of up to twenty elements in each sample, are designed to show differences in the behaviour of different elements, and so to illustrate the nature of the processes involved in soil development and plant uptake. A paper dealing with various aspects of trace element behaviour in soils, presented to a National Agricultural Advisory Service Open Conference of Advisory Soil Chemists in February, 1966, is awaiting publication[53].

Soils and Soil Parent Materials. The profile samples from Sheets 7/8 (Girvan/Carrick) submitted for analysis by Soil Survey have been examined for total trace element contents and the extractable contents in most of the selected profiles have been determined. The total trace element contents of the soils in this area vary quite markedly in the different associations. The contents of cobalt, nickel, chromium and copper are relatively high in the Darleith and Benan Associations which are derived at least in part from ultrabasic rocks, low in the Dalbeattie Association derived from acid igneous rocks and intermediate in the soils of the Ettrick Association of mixed sedimentary and metamorphic origin. Preliminary work is in progress on several profiles of podzols with iron pans from various locations throughout Scotland. These soils present many points of interest as far as the behaviour of trace elements in the pan and neighbouring horizons is concerned.

Soil Status and Plant Uptake. Analyses of plant materials and soils from the field experimental investigations of Soil Fertility have continued. These have involved studies of the effect of liming and manuring on trace element uptake and of short-term and residual effects of trace element additions. In addition some 2500 determinations of extractable cobalt, copper and molybdenum have been made for diagnostic purposes in soils on which trace element disorders have been suspected.

The investigation of the trace element content of various agricultural crops at different stages of growth has been continued. This involves the analyses of different plant parts, in order to determine the most appropriate stage of growth and the most suitable types of sample to be used in assessing trace element status. Crops being studied include barley, oats, cabbage and swedes.

The lead content of plant material is attracting increased attention, largely because of the surface contamination resulting from the exhaust fumes of motor vehicles. It has been known for some time that the lead content of pasture herbage, even in areas remote from roads carrying an appreciable

amount of traffic, increases substantially in autumn and winter and results demonstrating this have now been published[15].

There is, however, also an appreciable widespread and continuous deposition of lead from the atmosphere, and tests are being made in the neighbourhood of one of the sites from which results are reported in the above mentioned paper in order to ascertain whether the rise in lead during autumn and winter could be ascribed to this effect. It cannot be a straightforward contamination by surface deposition as little or no increase is apparent during the summer, but possibly appreciable surface accumulation occurs only after transpiration has ceased. A number of experiments involving some form of protection of herbage from direct atmospheric deposition are also being made.

Further work in progress on lead includes studies of possible residual effect of lead deposited on and incorporated into soils adjoining main roads. A comparison of similar soils sampled near and at some distance from such roads, obtained from two locations in England in collaboration with the National Agricultural Advisory Service, is being carried out in pot culture experiments with the assistance of Soil Fertility.

Investigations into the possible detrimental effects of sewage sludge continue. Analyses of crops grown in pots at various National Agricultural Advisory Service centres have shown that large amounts of some elements, particularly nickel and zinc, are present in available form in certain sludges.

Spectrochemical Methods of Analysis

No major modifications in techniques have been introduced. Preparations are being made for the installation of a Hilger and Watts Three Meter Grating Polychromater late in 1967. These include alterations to ancillary apparatus such as arc stands and provision for suitable current supplies in the laboratory that will house the equipment. To take full advantage of the increased facilities, appropriate sets of standard mixtures of trace elements in various matrices are being prepared.

Pretreatment and Concentration. In materials such as bone ash which are composed essentially of calcium phosphate it has proved possible to determine trace elements such as cobalt or molybdenum down to 0·01 ppm level using a 5 g initial sample. This has been achieved by carrying out a preliminary 8-hydroxyquinoline—tannic-acid—thionalide precipitation on the material brought into solution by acid extraction followed by sodium carbonate fusion. Thereafter, after ashing, the precipitate is re-dissolved and treated in the manner described in Annual Report No. 35, precipitation in each case being carried out in a volume of about 700 ml. The concentration technique has therefore shown itself fully capable of modification to cope with materials, including biological samples, in a phosphate matrix. Only if the iron content of a sample is high do difficulties arise in materials of agricultural or biological significance.

Arc Emission. A thorough investigation of the performance of the various modes of operation of the cathode-ray display microphotometer described in last year's report has now been carried out, and the results compared with those given by Hilger non-recording and Leeds-Northrup recording microphoto-

meters. The results obtained by the non-recording and pen-recording modes are in correspondence with those obtained with equivalent commercial instruments. The characteristic curves obtained with the different instruments decrease in slope as the scattered light increases. This is particularly well illustrated by the curves obtained by means of the display microphotometer, in which there is possibility of scattering at several points and with which the effect is greatest with strong lines and negligible with weak lines. The instrument is particularly well adapted for the measurement of weak lines, using the simple background correction technique. In addition to its use in extending the limit of determination for a number of elements, satisfactory tests have been made of the application of the display microphotometer to the determination of total contents of trace elements in soils and rocks, using the three-step sector mentioned in last year's report. Details of the performance were given in an invited paper[54] presented at the XIII Colloquium Spectroscopicum Internationale in Ottawa.

Preliminary tests prior to the introduction of the large direct reader suggest that it will be possible to use modified electrodes with a somewhat deeper, narrower bore for the cathode layer arc analysis of plant ash, particularly for copper, manganese, barium and strontium. It will thereby probably be possible to reduce the number of duplicate analyses, as the reproducibility appears to be improved. The change to a new instrumental technique will be an appropriate time to introduce other modifications whose applicability has been established.

Flame Emission. The demands from other departments for the determination of potassium, sodium and calcium in solution have continued at the previous levels and are met by flame photometric analysis. No modifications in techniques have been introduced.

Direct Photometry. The measurement range of the Hilger medium direct reader has been further extended by the incorporation of a plug-in capacitor unit which can be introduced in parallel with any integrating capacitor should its charge be too high for measurement even with a shunted meter. This unit extends the upper limit of the range by a second factor of three, and has proved particularly useful in the determination of silicon in plant ash by the rotating disk triggered a.c. arc technique.

Atomic Absorption. This technique is now employed for the determination of extractable cobalt in soils whenever no other acetic-acid-extractable constituent is required. A full description of the method and of the means of correction for interference effects is about to be published[55]. A second instrument suitable for use with a variety of flames employing acetylene or butane with air or nitrous oxide is in course of construction. Provision is being made for the use of atomic fluorescence methods with either line sources or a 450 W xenon arc continuous source. The instrument is being built around a monochromator from an early model Hilger H700 Uvispek which has the advantage of independently adjustable entrance and exit slits. A Techtron stainless steel burner-nebulizer unit is being employed and should eliminate the zinc contamination encountered in earlier tests of atomic fluorescence (Annual Report No. 36, 1965/66) using a brass-tubed burner.

Absorption Spectrometry of Soil Constituents

Unique information on the structure and composition of layer silicates can, in favourable cases, be obtained from the study of their lattice hydroxyl vibrations. The frequency of a hydroxyl vibration is determined, in part, by the ions to which it is linked, and this permits the identification of these ions, and of their valency state, by infrared methods. The present state of our knowledge of these topics has been discussed in a paper read to the Groupe Français des Argiles[56]. Of particular interest in soil chemistry is the possibility of following the oxidation and reduction of iron combined in layer silicates. It has been shown that ferric ions in the montmorillonite structure can readily be reduced to the ferrous state at room temperature, and reoxidize in air. Oxidation of ferrous ions in biotites and vermiculites, a common pedogenic process, has been followed in the laboratory, infrared spectra having shown that this process leads to ejection from the silicate lattice of a proportion of the ferric ions formed. A review of the use of infrared methods to characterize soil minerals awaits publication[57].

A paper dealing with infrared investigations of clays and their interlayer complexes carried out at the Macaulay Institute has now been published[16]. This paper is principally concerned with the results obtained, and a complementary paper[58] describing techniques developed during these investigations, illustrated by some recent applications, has been prepared, by invitation, for the ninth International Congress of Soil Science to be held in Adelaide. Examples of the use of these techniques include thermal stability studies[17] of tobermorite, a calcium silicate, and studies of interlayer adsorption complexes of montmorillonite with nitrobenzene and benzoic acid[18, 19], discussed in previous Annual Reports. Differential thermal investigations of benzoic acid complexes of montmorillonite led to the recognition that certain thermally inert diluents, commonly used in differential thermal analysis, are not chemically inert. This work has been pursued in collaboration with Pedology, and has led to the recommendation of calcined diatomaceous earth as a thermally and chemically inert diluent for use in the differential thermal analysis of organic samples[43]. A study[82] of the mechanism of adsorption of 3-aminotriazole by montmorillonite showed that, as with other organic bases and ammonia, this base is protonated at the clay surface.

Collaborative studies with Microbiology and Biochemistry have been principally concerned with the characterization of the constituents of fungal cell walls, and with the effect of partial lysis on the overall composition. Infrared spectra permit a rapid assessment of the major constituents—commonly chitin and various glucose polymers. The cell wall of *Mucor ramannianus* has proved to have an unusually high phosphate content, the source of which was identified from its infrared absorption as a linear condensed polyphosphate. A study of the lysis of this cell wall has been submitted for publication[59]. Infrared methods continue to contribute to the study of soil wax fractions (*see* Biochemistry), and both ultraviolet and infrared techniques were applied in a collaborative study, with Microbiology, of the metabolism of lignin and compounds related to lignin, which has now been published[20].

BIOCHEMISTRY

Although the technique of chromatography was developed early in this century it was not exploited fully until the 1940s when the partition chromatogram was given a firm theoretical basis by Martin and Synge and in the form of the paper chromatogram became one of the most powerful analytical tools at the disposal of the biochemist. Publications from the Institute in 1950 already described its application to soil organic matter.

The paper chromatogram was not suitable for separation of substances insoluble in water and two further techniques, gas liquid chromatography and thin layer chromatography, had to be developed before lipids could be separated as easily as sugars or amino acids. When the department acquired equipment for gas liquid chromatography in 1961 an investigation of soil lipids was begun, some results of which were briefly referred to in the last Annual Report.

Continuous extraction of mineral soil with alcohol-benzene mixtures dissolves about 2·5 per cent of the organic matter fraction; about 20 per cent of this is recognizable as lipid. A *Phragmites* peat gave rather higher figures: 5·5 per cent, 30 per cent respectively. Little can be said about the non-lipid part, except that there is evidence for the presence of polynuclear aromatic hydrocarbons; it is possible that it also includes humic acids of low molecular weight.

The lipid fractions have been resolved chromatographically and rather less than half of each identified by chromatographic procedures[21]. The main components are fatty acids having unbranched chains of 18 to 32 carbon atoms, even numbers, particularly 24, 26, 28 and 30, predominating. Related hydrocarbons, methyl ketones and alcohols accompany them. The composition of the mixtures is consistent with their origin in higher plants.

Further attention to the method of extraction has shown that a preliminary treatment of the soil with dilute aqueous hydrochloric and hydrofluoric acids enables organic solvents to extract 50 per cent more material. This is more acidic in character and less rich in lipids. The present aim is to find solvent mixtures combining efficiency, selectivity and economy of operation, so that a greater proportion of the material can be identified.

Dr R. I. Morrison has written a review of existing knowledge of soil lipids for a book on *Organic Geochemistry* now in preparation[61].

As in all previous investigations of soil organic matter much help has been given by Spectrochemistry, especially in the provision and interpretation of infra-red spectra.

Studies of soil sugars (Annual Report No. 35, 1964/65) have been assisted by the development of more sophisticated techniques. These include a separation of sugar mixtures in the form of their borate complexes, on columns of ion exchange resin, in which the effluent from the column is analysed continuously, permitting quantitative analysis of the mixture and also collection of samples for isotopic analysis. A visiting worker with a special interest in identification of rare sugars (Mr J. -F. Bouhours) collaborated in the applica-

tion of gas liquid chromatography to the minor components of the soil polysaccharides. In previous years these sugars had been the subject of several publications by the late Dr R. B. Duff. Further evidence was obtained for the presence of 2-O-methylxylose, but the use of these more advanced techniques revealed the presence of as many as eight sugars accompanying this sugar on paper chromatograms.

The techniques mentioned are being developed to determine the fate of radioactive polysaccharides added to soil (Annual Report No. 35, 1964/65), experiments on which have been resumed following the return of Dr M. V. Cheshire from a year's secondment to work with Professor R. D. Haworth in Sheffield[83].

Other Topics

Continued collaboration with Plant Physiology has led to a fuller understanding of the factors influencing the development of invertase in disks of storage tissue from red beet and various other species[22, 62, 63]. The proportion of the enzyme present in a soluble form has been shown to vary with species[23]. Dr D. Vaughan gave a paper on the stimulatory effect of humic acid on invertase development to the symposium *Humus et Planta*, held in Prague in September, 1967[64].

Biochemical studies of the lysis of fungal cell walls in collaboration with Microbiology and Spectrochemistry[24] (Annual Report No. 36, 1965/66) have been extended to *Mucor* species[59], and to certain yeasts. In the latter the walls have been shown to contain an α-glucan first tentatively identified in this Institute in the bracket fungus *Polyporus betulinus* (Annual Report, 1951/52), and more recently found in *Aspergillus*. A culture filtrate from a streptomycete species that lyses cell walls containing the α-glucan will attack the polysaccharide *in vitro*. The existence of an enzyme with this specificity has not previously been recorded, although it seems likely that the glucan is very widely distributed in fungal tissues. Dr Bacon read a paper on this subject to the seventh International Congress of Biochemistry in Tokyo in August, 1967.

Visiting Workers

Mr F. Megusar completed his year in the department as an I.A.E.A. Fellow. His experiments on the mineralization of soil nitrogen included some in which ^{15}N-labelled ammonia was added. These showed that some ammonia was being incorporated into insoluble (presumably organic) form simultaneously with mineralization. This provided further evidence that microbial growth was involved.

Mr J. -F. Bouhours of the Laboratoire de Physiologie Végétale de l'Institut Catholique of Toulouse worked in the department from May to September, 1967, with a bursary from the British Council. As mentioned above, he helped in the development of chromatographic methods for the identification of the soil sugars.

PLANT PHYSIOLOGY

Dr A. E. S. Macklon spent the academic year at Washington State University, Pullman, Washington, working on membrane potentials and ion flux measurements in collaboration with Professor N. Higinbotham. Dr I. R. MacDonald attended a conference at Wageningen and Dr P. C. DeKock read a paper on mineral metabolism of nitrogen at a symposium at Leeds University. Mrs A. M. Innes successfully submitted a thesis for the degree of Ph.D. to the University of Aberdeen.

Mineral Nutrition

A further series of experiments was made on the severe copper deficiency induced by applied nitrogen on oats grown on a peat with low copper content[26]. The severity of the deficiency is greater with ammonium nitrogen than with nitrate nitrogen. Separation of plant proteins on sephadex has been started to note the difference induced in oat plants by these two forms of nitrogen, and to see if any fraction has the copper associated with it. An earlier study of the growth of oats in nutrient solutions has been submitted for publication[68].

A collaborative study on chlorosis in pear leaves has been completed. It was earlier shown that chlorosis showed a close relationship with the phosphorus-iron ratio, but not with any single constituent. Relationships with citric and malic acids and with the potassium-calcium ratios were also found, as previously in mustard leaves.

A paper on physiological gradients in potato tubers has been published[27].

The association between iron and phosphorus in wheat and other grains and tubers has led the department to study inositol phosphates in some detail. Separation on Dowex columns as well as by paper chromatography is now a routine procedure. The chemistry of the iron complexes of the inositol phosphates is very complex and will require detailed study. Autoradiography using ^{59}Fe has shown that the iron in the wheat grain is largely confined to the aleurone layer, as also is the phosphorus.

Ion Uptake and Related Studies with Storage Tissue Cells

Two factors in particular have recently caused increasing attention to be focused on the metabolism of storage tissue disks. One is the possibility that the dramatic upsurge in metabolic activity associated with the slicing of storage tissue may be analogous to the mechanism of dormancy break in general. The other is the obvious suitability of this tissue for the investigation of many of the problems associated with the science of molecular biology. This suitability springs from the fact that slicing storage tissue apparently triggers off a *de novo* synthesis of enzyme proteins, for example, invertase synthesis in beet tissue, suggesting that a derepression of gene activity occurs in the sliced root leading to the synthesis of both messenger and ribosomal ribonucleic acid.

The development of a capacity for ion absorption is one of the most substantial changes that follows slicing and the relation of this development, and also of the mechanism of ion absorption, to protein synthesis has been

investigated[22]. Protein synthesis undoubtedly occupies a key position in this development and the activation of protein synthesis consequent to slicing has been studied using cell-free fractions. It has been shown[28] that a microsomal fraction from sterile aged beet disks can incorporate leucine into protein when supplemented with the supernatant fraction and the usual additives. In freshly cut disks the amount incorporated is very much less and since the ribonucleic acid content of the microsomal fraction increases with aging, the increase in incorporating ability could result from the synthesis of messenger ribonucleic acid. The sensitivity of this system to protein synthesis inhibitors is consistent with the results previously obtained with intact slices in respect of the development of ion uptake capacity, and it would seem that this development is linked to changes at the ribosomal level.

Investigations on invertase synthesis in beet disks have continued in collaboration with Biochemistry and have formed the subject of three communications[23, 62, 63]. Invertase is a particularly useful marker in studying the changes consequent to slicing, since it is virtually absent from the uncut root. In thick disks invertase synthesis commences in all the cells, but after some hours further development is confined to the outer cells, indicating that although derepression occurs in all the cells, the internal cells are subjected to some further restraint. Respiration is known to be affected in the same way and it has been shown[29] by an analysis of the effect of temperature on respiratory rate in terms of the Arrhenius equation that oxygen diffusion is the rate-limiting factor.

Papers dealing with the effect of sterile and non-sterile conditions on ion uptake[30] and electrical potential measurements in relation to ion uptake[31] have been published during the year under review.

Ion Fluxes and Cell Transmembrane Electrical Potentials

In assessing the significance of cell transmembrane electrical potentials in ion transport, the most straightforward situation to analyse is that where the cells are at flux equilibrium, that is, when uptake and loss of the ion under study are equal. In these circumstances, the relationship between the electrical potential (E) and concentration gradient, for an ion which is passively distributed, can be expressed as

$$E = \frac{RT}{z_j F} \ln \frac{C_j^o}{C_j^i} \qquad \text{(I)}$$

where C_j^o and C_j^i are the external and internal concentrations respectively of the ion j, z is the valency of the ion, R is the gas constant, T is the absolute temperature and F is the Faraday.

Thus, if the measured value of E is the same as that to be expected from the concentration ratio using equation I, the ion can be considered to be in passive equilibrium and no expenditure of metabolic energy by the cell is necessarily required to maintain what may be a considerable concentration gradient.

This relationship is of some use also in assessing the nature of ion transport in an accumulating system, where there is a net influx of the ion, such as in exuding root systems. However, in instances where the internal ion concentration is lower than would be predicted from the observed potential difference, no distinction can be made between the functioning of an active ion "pump" in an outward direction and the restriction of diffusion in an inward direction. To yield more conclusive evidence on such a point the following relation, which takes into account the separate fluxes, must be used

$$\frac{J_{in}}{J_{out}} = \frac{C_j^o}{C_j^i \exp(z_j FE/RT)} \qquad \text{(II)}$$

where J in and J out are influx and efflux respectively of the ion j, and the other symbols have the same meaning as in equation I.

This formula is of general validity for the independent passive movement of ions and if the experimentally determined values of each of the parameters satisfy the equation, the net flux of the ion concerned can be considered to be the result of passive diffusion. In collaborative work in the Department of Botany, Washington State University, this relationship (Equation II) has been used as the basis of an analysis of potassium fluxes and cell electropotentials in pea epicotyl segments.

When fresh cut segments of etiolated epicotyls are incubated in a complete nutrient solution including 1 mM KCl, there is, after a delay of about 8 hours, a marked uptake of potassium which reaches its maximum after about 24 hours. Comparison between net uptake, measured by analysis of K^+ contents, and apparent influx, established from the uptake of the radioisotope ^{42}K, indicates that efflux of K^+ is very small throughout the incubation period. This has been confirmed by direct measurement of efflux from tissue preloaded with ^{42}K. It is evident from these findings that an active uptake of K^+ occurs, but a more detailed analysis of the efflux data is necessary to determine at what point in the cell the active mechanism is located.

Since in a vacuolated plant cell there are two membranes which are considered to be important in regulating the diffusion of ions, one bounding the cytoplasm and another bounding the vacuole, values for each of the parameters J in, J out, C_j^i and E in equation II are needed for each cell compartment, so that the equation can be applied to each compartment separately. From an analysis of the compound efflux curve, constructed from measurements of ^{42}K appearing in unlabelled nutrient solution from tissue incubated 24 hours, values of J out for both cytoplasm and vacuole have been obtained, and the quantity of K^+ in each compartment determined. On the basis of estimates of the volume of each cell compartment, these content values can be converted to the concentrations appropriate for use in equation II. The overall cell potential at 24 hours is -128mV (between bathing solution and vacuole) and, as far as can be determined, a large part if not all of this potential would seem to reside across the outer membrane.

On the basis of these experimentally determined values, the separate K^+ fluxes measured across the outer membranes are those predicted by electro-

chemical diffusion theory, that is, the values fit equation II, and K^+ movement into the cytoplasm would seem to be passive. In the vacuole, however, the concentration of K^+ is much too high to be accounted for in passive terms, and it must be concluded that K^+ is actively pumped into the vacuole from the cytoplasm, that is, the site of the active uptake mechanism would appear to be at the inner membrane.

Radioactivity

The radioactive tracer technique has continued to be used by Plant Physiology, Biochemistry and Soil Fertility. Ryegrass labelled to high specific activity has been produced for the Rowett Research Institute, to be used ultimately in experiments in animal nutrition. The fractionation of the plant material into complexes containing zinc provides interesting information on plant chemistry, in addition to supplying material for the animal experiments. This technique of fractionation of labelled material should be applicable to certain other trace elements.

Cerenkov radiation is light which is detectable by photomultipliers when high energy beta emitting isotopes are in aqueous solution. This attractive technique can be used with isotopes such as ^{32}P and ^{42}K with simple sample preparation and high sensitivity when counted in a liquid scintillation counter. The method has been investigated with the manual change liquid scintillation counter, but for work of this type automatic sample change equipment would be advantageous.

A radiochromatogram scanner for paper and thin layer plates has been acquired and is being used for work with ^{14}C by the Biochemistry department.

MICROBIOLOGY

The main lines of work outlined in last year's report have been continued. Progress made during the year in the various investigations is given below. Collaboration with other departments within the Institute has been maintained.

During the year Mr M. P. Greaves attended a symposium on naturally occurring phosphoric esters held in Newcastle in July. Dr Darbyshire attended a meeting of the British section of the Society of Protozoologists at Norwich in April. Dr Jones presented a paper to the British Mycological Society in London in November, and also attended a meeting of the same society in London in September. He gave demonstrations on the ultrastructure of fungi at a symposium of the Royal Microscopic Society in Leeds in April, at a conversazione of the Royal Society of Edinburgh in July and at a meeting of the Scottish Ultrastructural Association in Aberdeen in May. Dr Jones also attended a meeting on electron microscopy in biology held by the Royal Microscopic Society in Nottingham in July and an A.R.C. Conference at Cambridge in September on instrumentation and techniques in electron microscopy.

Rhizosphere Studies

Papers dealing with the protozoan rhizosphere populations of perennial ryegrass (S23) growing under field conditions and with protozoan and bacterial populations of white mustard, white clover and perennial ryegrass growing under controlled environmental conditions have now been published[32,33]. Under the latter conditions a study of the protozoan and bacterial populations in rhizosphere and unplanted soil showed that both populations increased in the rhizosphere at an early stage in the growth of the plant and very soon exceeded those in unplanted soil. The maximum difference between rhizosphere and unplanted soil for both groups of organisms occurred during the early flowering period of both the white mustard and white clover plants. The protozoan genera in the rhizosphere and unplanted soils were identical, although the relative abundance of particular genera varied considerably with plant species and age. Desiccation of soil in which ryegrass plants were growing caused an initial reduction in the numbers of protozoa and bacteria in the rhizosphere. Later the numbers increased and sometimes exceeded those found in soil maintained in a moist condition. The numbers in unplanted soil were not so markedly affected by desiccation. Encystment of the protozoa was found to occur in both wet and dry rhizosphere and unplanted soils and it is clear that desiccation alone was not responsible for encystment.

An apparatus for aseptic cultivation of plants in controlled environments has been developed and is undergoing test. It is hoped to study the interrelationships of plants and rhizosphere micro-organisms with this apparatus.

Microbial Decomposition of Organic Phosphates

Full details of the study of the hydrolysis of inositol phosphates by an enzyme from *Aerobacter aerogenes* have now been published[34]. The

collaborative study with Soil Fertility on the mineralization of inositol phosphates in soil and sand has continued. It has been shown that in sand inoculated with a suspension of soil micro-organisms myoinositol hexaphosphate is rapidly broken down, inorganic orthophosphate accumulates and the microbial population increases. No evidence has been found to show that this occurs in soil. Addition of clay minerals (kaolin and montmorillonite) to the sand cultures caused a decrease in the amount of mineralization of inositol phosphate. The presence of iron or aluminium had a similar effect.

The study of the breakdown of nucleic acids by soil bacteria has been extended. A wide range of techniques have been employed to demonstrate the extent of hydrolysis which occurs and to estimate and identify the products of hydrolysis.

Lignin Decomposition

The work on the ecological and physiological aspects of fungal degradation of lignin and related aromatic compounds using the pellet technique developed in the department has now been published[20]. An unusual fungus was isolated during this study and an electron microscope investigation of the spores and hyphae of this organism revealed some interesting features. A paper incorporating the results has been accepted for publication[69]. The fungus has also been examined by Dr A. Onions of the Commonwealth Mycological Institute, Kew, and shown to be a new species of *Acremoniella*.

Spores and mycelium of this fungus and others, namely *Aspergillus*, *Tilletia*, and *Ustilago*, have been examined in a scanning electron microscope and the fine structure of their spore surfaces studied. The results obtained show that the technique used could be a valuable aid in fungal taxonomy. Papers describing these results have been submitted for publication[70,71].

Lytic Soil Micro-organisms

The results of the work on the lytic activity of the non-fruiting myxobacterium *Cytophaga johnsonii* on the cell contents of the eubacterium *Aerobacter aerogenes* and on the walls of the yeast *Saccharomyces cerevisiae* has now been published[11]. Descriptions of the lytic activity of two soil fungi on this yeast[35] and of the location of chitin in its walls[24] have appeared.

Streptomyces spp. isolated by means of a new enrichment technique[72] have been shown to be active in lysing isolated cell walls of *Mucor ramannianus*, a saprophytic soil fungus, and also the walls of the root pathogen *Fusarium culmorum*. This work, which is being carried out in collaboration with Biochemistry and Spectrochemistry, has been expanded to follow in detail the ultrastructural and chemical changes that occur in walls of different morphological structures (hyphae, sporangiospores and arthrospores) of *M. ramannianus* during lysis by one of the *Streptomyces* spp. A paper incorporating these results has been submitted for publication[59]. A similar study has been made on the cell walls of two soil yeasts, *Cryptococcus albidus* and *Cryptococcus terreus*. This work is continuing.

A note describing a new technique for locating fungal material, particularly after partial lysis, in araldite blocks for ultra-thin sectioning has been published[10].

Localized Activity of Soil Micro-organisms

A detailed account of the pellet and aggregate techniques developed in the department for the study of the localized activity of micro-organisms in soil has been accepted for publication[73].

SOIL FERTILITY

The research programme is designed to clarify the nature and significance of the fundamental soil constituents, properties, processes and conditions which govern nutrient supply, fertilizer requirements and crop production, and which underlie the influences of pedological factors, especially parent material and drainage conditions. The coverage ranges from purely chemical laboratory investigations on the forms of occurrence and reactions of nutrients in different soil types, through detailed studies on nutrient uptake and the mineral composition of plants, to more direct practical questions, especially optimal forms, rates, times, frequencies and methods of application of fertilizers for different crops and soils. Dr B. W. Bache joined the department in October, 1966 to undertake the main responsibility for developing detailed physico-chemical studies on relevant aspects of soil-nutrient-plant relationships, and a start has been made in this direction. Overriding importance continues however to be placed on the principle of concurrent development and integration of field, pot and laboratory studies, based on a selection of contrasting soil series mapped in the soil survey of Scotland and covering the main agricultural crops.

The latter principle is especially important in relation to the improvement and calibration of laboratory methods for evaluating soil nutrient status, which remains a major objective of the research programme. The practical application of such methods is also an important part of the department's responsibilities, and advisory soil testing activities have been continued in collaboration with the North of Scotland College of Agriculture. As in the past, practical applications of research findings have also been furthered by contributions to the agricultural press, talks to various agricultural and horticultural bodies, and representation on technical committees, especially the Technical Committee on Soil Fertility of the Agricultural Research Council, the Grassland Committee of the Scottish Agricultural Improvement Council, and the Scottish Sub-committee of the Sugar Beet Research and Education Committee. Contributions have also been made to a discussion group on Hill Land Use and Ecology and to a working party on the future of Fertilizer Practice Surveys in Scotland, while normal collaboration has been maintained with other research organizations, especially the Rowett Institute and the Hill Farming Research Organisation.

New pot experiment enclosures installed three years ago are proving very satisfactory, and have greatly facilitated the practical work. Under the old system the pots were immobile on fixed benches in a simple netted cage. This had the restriction that it was not possible to undertake experiments involving full control of water supply, and it also had the disadvantage that the pots often became undesirably wet during heavy rainfall and the results were occasionally vitiated in this way. But there were also the advantages that the growth environment was relatively uncomplicated, with minimal position variation, and that most of the time the rainfall provided very suitable watering and saved much time and labour. To retain these advantages and

remove the disadvantages, the new installation contains a simple cage covered with plastic coated wire netting and joined to a corresponding enclosure with netted sides but a glass roof, while the pots are carried on trolleys running on connecting rails extending nearly the full length of the two areas, so that they can be easily and quickly moved from the one to the other. There are eight sets of 2 feet wide rails, with 5 feet passages between them, and each set carries two trolleys each holding 40 Mitscherlich type pots. This gives full flexibility because the total complement of 640 pots can be used in either enclosure as required, depending on weather conditions and the degree of moisture control desired. The roofed enclosure also protects the pots and trolleys over winter and greatly facilitates the initial setting up, the sampling and harvesting, and the carry over of pots from one season to another. To achieve this flexibility required rather large enclosures, each approximately 60 feet wide by about 70 feet long. In addition it was desired to extend the facilities for future developments by having a fully glazed greenhouse of 60×14 feet joined to the roofed enclosure, to give three types of growth environment and levels of control. By utilizing the appropriate standard components of a commercially available aluminium alloy glasshouse it was possible to obtain all three structures on a common basis and at an acceptable cost.

Much improved facilities have also been obtained to serve field experiment requirements, in the form of a new building comprising a garage for vehicles and implements, a main section for storing fertilizers and dispensing supplies for individual experiments and plots, a more elaborate small store for special fertilizers, and a room for the field staff. During the year experiments were carried out at 54 centres, chosen in consultation with Soil Survey to represent different soil series. Grateful acknowledgement is made of the willing and efficient co-operation of the farmers concerned, without which the programme would not be possible.

Dr W. M. Crooke attended a Symposium on Aspects of Nitrogen Metabolism and Utilization in Plants at the Long Ashton Research Station, University of Bristol, on 18-19 April, 1967, and Dr G. Anderson took part in an International Symposium on Naturally Occurring Phosphoric Esters, arranged by the Chemical Society, in Newcastle-upon-Tyne on 10-12 July, 1967. At the invitation of the Consejo Superior de Investigaciones Cientificas and the Instituto de Edafologia y Biologia Vegetal, Madrid, Dr E. G. Williams contributed a paper[38] to a special international issue of *Anales de Edafologia y Agrobiologia* published in memory of the late Professor J. M. Albareda, the first Secretary of the Research Council and the first Director of the Institute.

Effects of Fertilizers on Crop Yield and Composition. Mention was made in last year's report of a joint paper with Statistics on the calculation of optimal economic rates of N, P and K for potatoes, using results from factorial experiments. This has now been published[36], and further field experiments using the central composite design are in progress on potatoes, swedes and cereals.

Methods of Applying Fertilizers. A new machine for combine drilling seed and fertilizers at ow widths from 3·5 inches upwards has been acquired.

This was designed and built by the National Institute of Agricultural Engineering and has been used in two preliminary experiments on cereals to compare the effects of broadcast and combine drilled phosphate at row widths of 3·5 and 7 inches.

Calcium and Magnesium. One of the two papers on magnesium mentioned in the last two reports has now appeared[37], but the other[74] is still in press. Field and laboratory work has been continued on the long term effects of various magnesian supplements and on the effects of other nutrients, especially K, on the magnesium content of crops and herbage.

Trace Elements. Field experiments and laboratory analyses of crop and soil samples have been continued in collaboration with Spectrochemistry. A joint paper[15] on the lead content of herbage, mentioned in last year's report, has now been published, and a pot experiment has been undertaken to obtain more information about the rise in lead content during the winter months, and on the probable effects of contamination of soil with lead from fuels used in motor vehicles. Experimental work on the effects of different rates of N, P and K on the trace element content of mixed herbage and some of the constituent species is being continued.

A paper[75] reporting the results from many years of field and pot experiment work on copper deficient soils in north-east Scotland has been accepted for publication. Spring-sown oats and barley are more susceptible to copper deficiency than mixed herbage, while potatoes and swedes have shown no response to copper even on soil deficient for cereals. This deficiency can be corrected by applying 10 to 20 lb $CuSO_4.5H_2O$ per acre to the soil, which is generally more effective than a foliar spray of 1 lb per acre. Both field and pot experiments have shown that the above soil treatment has a large residual effect and under field conditions is effective for at least eight years. Using soil undiluted with sand, the increase in grain yield produced by copper treatment in pots is appreciably greater than in the field, the average responses for copper deficient soils being 117 and 20 per cent, respectively. In both field and pot experiments statistically significant correlation coefficients have been obtained between soil copper extracted by 0·05M EDTA, and the increase in grain yield produced by soil applications of copper. Under field conditions in north-east Scotland it appears that the yields of spring-sown cereals are not restricted by a deficiency of copper if the EDTA extractable copper is above 1·1 ppm. With soil content below 0·75 ppm copper the grain yields are usually increased considerably by copper treatment, while there may be a small response at contents between 0·75 and 1·1 ppm.

Inorganic Phosphorus. Long term field experiments have been continued on the residual effects of superphosphate and ground mineral phosphate in different soil types. Individual experiments are gradually completing their full course and the series as a whole is due to be finished in the next two or three years. Major attention in both the field and pot experiments, especially the latter, has again been concentrated on the effectiveness of various phosphate compounds, with the main emphasis on the effects of extremely fine

grinding, down to less than 1μ, with and without the incorporation of sulphur, on the availability of various rock phosphates. The pot programme included also an experiment on the interactions of dressings of inorganic P and inositol hexaphosphate, and an examination of the behaviour of various other organic phosphorus compounds, originally tested as possible P sources but which appear to have some characteristic physiological effects.

Laboratory investigations have been continued on the phosphate relationships of different soil types. An account has been published[38] of further studies on the interpretation of the relative and absolute usefulness of various types of P extraction values as criteria of P status on the basis of their quantity-intensity balance. The latter characteristic can be assessed from (a) the correlation of the value with the dry matter yield compared with the P uptake of the crops, the former being more intensity dependent than the latter, (b) its relationship with the ^{32}P " L value " as the reference quantity measurement compared with water and $CaCl_2$ soluble P as intensity standards, and (c) the extent and variation from soil to soil of the partition of the soluble P between the solid and liquid phases. The latter can be qualitatively judged from the nature of the extractant and the extraction conditions, especially the displacing power of the anion, the pH and the extractant: soil ratio, and can be quantitatively estimated from the magnitude and variation of the recovery of P added to the suspensions, low recoveries and high variation indicating a strong intensity bias. The results confirm that the two main factors governing the significance and usefulness of conventional extraction values under different soil and crop conditions are the extent to which they are liable to reflect sources of soil P which are not available to plants and the quantity-intensity balance as assessed in the above ways. They also show that in Scottish agricultural soils, with their generally high but very variable P retention capacities and contents, reflection of the quantity factor is still necessary, but the dominant criterion in relation to yield is the intensity of the P supply and the most important single common factor regulating this is the degree of P saturation of the soil.

In view of its central importance, detailed physico-chemical studies have been initiated to examine the possibilities of obtaining improved estimates of the degree of P saturation of soils from more refined measurements of P retention capacity, based on adsorption isotherms, in conjunction with exchangeable P measured with ^{32}P.

Sulphur. Studies on the sulphur relationships of contrasting soil series have been continued with special reference to the long-term effects of the use of sulphur-free fertilizers and the implications of parent material and drainage conditions in relation to sulphate sorption and retention and to the distribution of various categories of organic and inorganic sulphur. A thesis covering the latter topics, submitted by Mr N. M. Scott to the University of Aberdeen in candidature for the degree of Ph.D., has been sustained.

Organic Phosphorus. A chapter dealing with the isolation and characterization of the phosphate esters in soil has appeared in a book on Soil Bio-

chemistry[39], and as mentioned in last year's report chapters on soil organic phosphorus[76] and organic sulphur[77] have been prepared for an Encyclopedia of Soil Science. The results of a co-operative study with Microbiology on the hydrolysis of inositol phosphates by *Aerobacter aerogenes* has also been published[34].

Measurement of the total organic phosphorus content of a number of Canadian soil profiles has thrown some new light on the validity of the results obtained by ignition and extraction methods. In nearly all cases the ignition value is much higher than the alkali extraction value, and is substantial even in the C horizon which contains very little organic matter. Ignition values are calculated from the difference in acid-soluble inorganic phosphate in ignited and unignited samples, and it has been concluded that in the C horizons the ignition values represent almost entirely the effect of ignition in increasing the solubility of inorganic phosphorus compounds. When the ignition values for the upper horizons are corrected by subtracting the corresponding value for the parent material, good agreement with the extraction values is obtained. A note on these observations has been submitted for publication[78].

It has previously been shown that up to one quarter of the phosphate in British soils occurs in the form of inositol penta- and hexaphosphates. Examination of a number of Canadian soils has now shown that the amounts in these are much lower not only in absolute terms but also in proportion to the total soil organic phosphate[79]. The amounts found are related to the contents of both total phosphate and total organic phosphate, accounting on average for 6 per cent of the former and 17 per cent of the latter. The inositol phosphates are highly correlated with orthophosphate retention capacity but the relationships with soil N and C are poor.

Publication is still awaited of an earlier paper, mentioned in the last two reports, on the determination of inositol hexaphosphate in soils[80].

Cation-exchange Properties and Mineral Composition of Plants. For several seasons extensive efforts have been devoted, in conjunction with Plant Physiology, to gathering the necessary experimental material for a comprehensive study into the differential distribution of cations between roots and leaves of plants in relation to the cation-exchange capacity of these tissues. The experimental work, which has now been completed, involved the sampling and mineral analysis of a wide range of natural vegetation, and agricultural and horticultural crops. Differences in cation and anion composition both within and between species are being examined.

A knowledge of the total content of each of the various plant nutrients at any one stage in a plant's life cycle yields pertinent information on nutritional requirements and differences between plant species, and rather more can be inferred if periodic samples are taken from the seedling stage through to maturity. A fuller insight into plant composition, however, becomes possible if the individual nutrients are subjected to fractionation into the different forms in which they occur in the plant, and a start has been made employing this approach for the common agricultural crops, with particular reference to major cations and nitrogen. In addition the influences of external environ-

ment and fertilizer rate are being studied by distributing the field experiments on contrasting soil types.

Advisory Work. Over 12,500 soil samples were analysed during the year. Most of these came from agricultural or horticultural land in the advisory area of the North of Scotland College of Agriculture, but a small number came from forest nurseries and were dealt with in collaboration with Pedology. Samples of soils and crops from areas involving crop growth or animal health problems continue to be examined for trace elements in collaboration with Spectrochemistry.

Attention has been drawn to the need for adequate liming to help to maintain and improve soil fertility. Assessment of the outstanding deficiencies of lime in rotation land in the advisory area of the North of Scotland College of Agriculture for the 1957-1967 period are set out in the accompanying table. It is clear that there was a continuing improvement up to 1962, but subsequently there has been no improvement and even a small increase in the outstanding deficiency. There is therefore still a clear need for continuing the policy of encouraging farmers to bring the lime status of the soil to a satisfactory level.

Lime Requirement of Rotation Land in the Advisory Area of the North of Scotland College of Agriculture.

Percentage distribution of advisory soil samples according to lime contents					Tons CaO required to correct outstanding deficiencies
Year	Very Low	Low	Slightly Low	Satisfactory	
1957	2	22	61	15	1,170,000
1962	1	9	61	29	896,000
1967	1	11	62	26	1,022,000

STATISTICS

The section provides a service for the various departments of the Institute, collaborating in the design of field, greenhouse and laboratory experiments and in the planning of sampling investigations.

Considerable quantities of data processing and statistical analysis have been carried out on the Elliott 803 electronic computer at the University of Aberdeen, and grateful acknowledgement is made to the University for this facility. A Westrex teletype, kindly lent by the Rowett Research Institute for the greater part of the year, improved facilities for the reading and punching of paper tape. The increase in computer use has required more time to be spent on programme writing and development, which is now an integral part of the work of the section. Preparations are already in hand for reprogramming in the appropriate language to take advantage of the offer of time on the computer shortly to be installed at the Rowett Institute.

General computer programmes in most frequent use are concerned with the processing and transformation of data, the analysis of designed experiments, tabulation of classified data, the calculation of correlation coefficients with tests of homogeneity and significance, the solution of equations, and the fitting of polynomial and exponential growth curves. The correlation programme has been of value to a number of departments where the initial investigations were concerned with examining relationships between elements in the same plant part, between plants or plant parts for the same element, and between elements in the soil and elements in the plant. Other computer tasks have involved plotting of data, polynomial interpolation, regression with estimation and tests of significance, the estimation of economic optima, and the calculation of similarity indices based on probability.

In collaboration with Soil Fertility, studies of the economic and plant nutrient content aspects of fertilizer application have continued. A joint paper[36] dealing with a method of estimating the optimal nutrient rates for potatoes, presented at the joint meeting of Commissions II and IV (Soil Chemistry and Soil Fertility) of the International Society of Soil Science in Aberdeen in September, 1966, has now been published. In an examination of the relationships between the response of swedes to phosphate and the soil phosphate extracted by various methods, both polynomial and exponential response curves are being considered.

Results from factorial experiments with oats grown in peat of very low copper content have been published[26], and a paper on oats grown in nutrient solutions has been submitted for publication[68]. Other collaborative studies with Plant Physiology have also required computer facilities for data processing and statistical analysis. In both designed experiments and surveys the relationships between inorganic and organic constituents have been examined for a number of plants and plant parts.

Conversion tables for regular reference in the interpretation of instrument readings have been generated by the computer for Pedology (Peat and Forest Soils). This is an intermediate stage which has removed some of the burden of laboratory calculations and indicates the further advantages to be gained

from direct processing by computer. The detailed study of the nitrogen nutrition of coniferous trees has continued and further sets of weekly girth measurements have been examined in terms of weekly growth rate and cumulative growth. ALGOL computer programmes were written for a comparison of the accuracy of three methods of prediction of forest totals for the weights of tree parts and the uptake in these parts of a number of elements. The most complex method used transformations and regression estimates of 77 quantities for each size class in the forest.

In collaboration with Pedology, Soil Survey and the Department of Statistics at Rothamsted, preliminary tests have been made on numerical methods for soil classification using the ORION computer. Acknowledgement is also due to Rothamsted Experimental Station for computer facilities to provide the analysis of potato yields, crop composition and soil data from a large series of factorial experiments and to investigate the relationship between botanical composition and various soil characteristics. For a sample of the botanical survey data, Elliott autocode computer programmes have been developed to explore the patterns of grouping of sampling points using a similarity index based on probability. The similarity is derived from a number of attributes—the botanical composition and/or the soil characteristics.

Co-operation with the North of Scotland College of Agriculture has been maintained in the design and analysis of experiments on carrot fly control, potato diseases and the storage and dressing temperatures of potatoes.

Collaboration with the Crop Husbandry Department of the West of Scotland Agricultural College has continued and further series of NPK factorial experiments on potatoes, swedes, barley and rape are in progress.

LIBRARY

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

Intake of stock is limited by the ever-rising cost of books and journals, but subscriptions to eleven additional journals were taken out this year and 176 books were added, 31 being received by gift or under the exchange agreements which contribute so much valuable material.

Co-operation in the inter-library lending schemes continues. This year borrowing was heavy, 984 applications for books and journals being referred to other libraries; 211 requests for loans were received.

The Institute maintains a mailing list of individual scientists and institutions interested in the various branches of the research work, and lists of staff papers of which reprints are available are periodically sent out. No charge is made for reprints and anyone interested in receiving the lists should apply to the librarian. This year 4839 reprints were distributed.

PUBLICATIONS

(A) *Published—*

1. The thermal analysis of lichens growing on limestones. By B. D. Mitchell, A. C. Birnie and J. K. Syers (Lincoln College, Canterbury, New Zealand). (*Analyst, Lond.*, **91**, 783-789, 1966).

   Lichens are frequently the first readily recognizable representatives of the biotic factor in soil formation. In the course of an investigation of the pedogenic activities of lichens growing on limestones, it was found that they varied greatly in their calcium oxalate content. Since chemical methods of determining calcium oxalate in plant materials are time-consuming, a detailed qualitative and quantitative study of oxalate in lichen species using thermal methods was carried out. The results show not only that thermal methods provide a rapid and reliable means of determining calcium oxalate in plant materials, but that they also permit assessment to be made of the carbonate inherited from the substrate.

2. Some advanced topics in clay mineralogy and in differential thermal analysis: Summaries of a course of lectures delivered to research students in soils at Cairo University during the period January-March, 1967. By R. C. Mackenzie. (Cairo University, Faculty of Agriculture, Soil Science Department. 1967. 88 pp.) *No reprints.*

3. Methods of mineralogical analysis of soils. By W. A. Mitchell. (pp. 49-52 of *Proc. (NATO) int. Study Grp. on Soils, Cambridge, 1964.* 1967).

   Soil is a complex system requiring the combined resources of chemical, mechanical and mineralogical analyses for investigating its genesis, composition and behaviour. Many of the recently developed instrumental techniques are applicable either to the soil as a whole, or, more often, to separated particle-size fractions. Some of the more important of these methods for mineralogical analysis are briefly described.

4. Some granitic and andesitic soils in north-west Turkey. I. General description of the soils. By A. Irmak and F. Gulcur (University of Istanbul) and W. A. Mitchell. (*Agrochimica*, **11**, 176-183, 1967).

   Two groups of forest soils in north-west Turkey are described, one on granitic rocks and the other on andesites. They occur under similar climatic conditions in areas characterized by Brown Forest Soils. The profiles are sited at high elevations (1300-1800 m) and they have high silt contents which can probably be attributed to frost action. The granitic soils are coarser in texture than those on andesite, and although some profiles of both groups show evidence of slight podzolization this is more common in those on granitic rocks.

5. Some granitic and andesitic soils in north-west Turkey. II. Analytical and mineralogical studies. By A. Irmak and F. Gulcur (University of Istanbul) and W. A. Mitchell. (*Agrochimica*, **11**, 237-245, 1967).

   The soils have been subjected to mechanical analysis and routine chemical tests and the clay and fine sand fractions have been analysed mineralogically using X-ray diffraction and optical methods. The granitic soils are lower in base saturation and cation-exchange capacity. The clay and silt fractions of the andesitic soils contain cristobalite derived from the parent rock. Differences in the clay mineralogy between the two groups are small and of less significance than differences in the clay contents.

6. Die Morphologie feinteilchenförmiger Oxide des Eisens, Aluminiums und Mangans. By R. C. Mackenzie. (*Staub*, **27**, 226-233, 1967).

   Finely particulate iron, aluminium and manganese oxides are common constituents of soils, and it is therefore valuable to have some information on their morphology. Despite the common occurrence of many of these oxides, the amount of electronoptical

data is somewhat sparse for many species. From a survey of available information it appears that few can be identified under the electron microscope on the basis of their morphology: some also crystallize in more than one form.

7. Distribution in some Scottish soils of an inorganic gel system related to "allophane." By J. H. Kirkman, B. D. Mitchell and R. C. Mackenzie. (*Trans. R. Soc. Edinb.*, **66**, 393-418, 1966).

   The various particle-size fractions of samples from the genetic horizons of five profiles representative of diverse and agriculturally important soils in north-east Scotland were examined in detail. Chemical dissolution methods were employed and their effects followed by a combination of instrumental techniques, including optical examination, X-ray diffraction, electron microscopy and diffraction, infrared absorption spectroscopy and thermal analysis. The results have enabled a semi-quantitative assessment to be made of the mixed silica-alumina-ferric oxide gel system occurring in these soils. Differences in the chemical composition and quantity of this system are observable between profiles and down each profile. The most marked differences are between the freely-drained soils and differences are less pronounced under conditions of impeded drainage. The degree of development of the soil is also an important factor. In general, the results can be interpreted in accordance with currently accepted pedogenic concepts.

8. The weathering of biotite in some Aberdeenshire soils. By M. J. Wilson. (*Mineralog. Mag.*, **35**, 1080-1093, 1966).

   The weathering of biotite in some freely drained soils developed from a biotite-rich quartz gabbro near Strathdon, Aberdeenshire, has been studied. Using a combination of X-ray, chemical, differential thermal, infrared and optical techniques, it was found that the biotite weathers to an intergrade aluminous vermiculite-chlorite together with zones of kaolinite and gibbsite. The crystallographic axes of biotite and the included kaolinite are common and parallel, and it is suggested that both kaolinite and gibbsite zones crystallized epitaxially within opened-out cleavage spaces of the host biotite. The development of kaolinite and gibbsite in this manner could have occurred relatively quickly and the significance of this with regard to generalized pedogenic weathering reactions of biotite is discussed.

9. The characterization of a peat profile by thermal methods. By J. M. Stewart, A. C. Birnie and B. D. Mitchell. (*Agrochimica*, **11**, 92-104, 1966).

   The appreciation of morphological differences within a peat profile and the evaluation of these in terms of physical and chemical properties is essential for the efficient utilization of a peat deposit. This investigation has shown that differential thermal and thermogravimetric techniques can be used to characterize the various strata in a peat profile. The effects of such factors as calorific value, particle size, humification, ratio of fibres to amorphous material, mineral matter and botanical composition are all to some extent reflected in the thermal curves.

10. The location of specimens in Araldite blocks for ultra-thin sectioning. By D. Jones and W. J. McHardy. (*Bull. Br. mycol. Soc.*, **1**, 39, 1967).

    A new technique is described which has enabled small amounts of fungal material, which is almost transparent after partial degradation by lytic soil micro-organisms, to be located in resin blocks before sectioning and subsequent examination in the electron microscope. This technique is also applicable to other biological materials and mineral specimens.

11. A comparison of the lytic action of *Cytophaga johnsonii* on a eubacterium and on yeast. By D. M. Webley, E. A. C. Follett and Irene F. Taylor. (*Antonie van Leeuwenhoek*, **33**, 159-165, 1967).

    In this paper an account is given of the lytic action of a non-fruiting myxobacterium *C. johnsonii* which, in previous work from the Institute, was shown to be present in

high numbers in the root region of certain pasture grasses. This organism has now been found to be capable of attacking the yeast and bacterial cells but in different ways. With autoclaved yeast cells the walls are lysed while those of autoclaved bacteria are unaffected. The organism can however digest the contents of the bacterial cells leaving the walls intact. Lytic organisms of this type play a major role in the decomposition of the initial microbial population when the latter becomes moribund, following its attack on plant residues added to soil.

12. Changes in weight and nutrient content of litter-fall beneath Corsican pine following application of nitrogen. By H. G. Miller and J. D. Miller. (*Pap. XIV Congr. int. Un. Forest Res. Org., Munich*, **2**, 335-351, 1967).

The effect of nitrogen applications on the weight and nutrient content of the litter-fall beneath a nitrogen-deficient crop of Corsican pine was measured over a period of 30 months. The results are discussed in relation to crop growth and the accumulation of organic matter and nutrients on the forest floor.

13. Soil survey of Great Britain: application to problems of engineering. By R. Glentworth. (pp. 68-74 of *Proc. (NATO) int. Study Grp on Soils, Cambridge, 1964*. 1967).

A brief description of the Soil Survey of Great Britain and the method of mapping using air photographs is given. The importance of parent material and drainage class is stressed. While the agricultural significance of these factors is well known, it is suggested that the units shown on a soil map, the soil series, would be found highly relevant to the civil engineer if measurements of soil mechanics were applied and studied on a soil series basis.

14. A method for measuring the iron-mobilizing capacity of aqueous extracts of plants. By J. W. Muir. (*Trans. VIII int. Congr. Soil Sci., Bucharest, 1964*, **3**, 529-533, 1967).

As part of an investigation into the movement of iron in soils, a method of measuring the mobilization of iron by an aqueous extract of Scots pine needles was developed. The method is based on the behaviour of ferric chloride solutions over a wide range of pH. The aqueous extract or one of its constituents modifies this behaviour and so provides a measure of its capacity to mobilize iron. Citric acid, a typical constituent of the aqueous extract, is used to illustrate the method.

15. The lead content of pasture herbage. By R. L. Mitchell and J. W. S. Reith. (*J. Sci. Fd Agric.*, **17**, 437-440, 1966).

The lead content of pasture herbage grown in the north-east of Scotland on soils with normal total lead contents of 10-50 ppm shows a marked increase from around 1 ppm during the growing season to as high as 10 ppm in late autumn and 40 ppm in winter. This effect does not appear to arise from any form of surface contamination of the herbage, and occurs in areas where exhaust fumes from leaded petrol and other industrial causes cannot be responsible.

16. Infrared absorption spectrometry in clay studies. By V. C. Farmer and J. D. Russell. (*Clays Clay Miner.*, **15**, 121-142, 1967).

Infrared studies on clays at the Macaulay Institute, directed towards characterizing the types of clay mineral which occur naturally in soils, and to obtaining information on the surface properties and reactivity of these minerals, are reviewed. New information is presented on features which distinguish beidellite from montmorillonite The presence of weak hydrogen bonds between lattice oxygens and interlayer water is established, although it is shown that the strength of hydrogen bonds formed between NH_4^+ and lattice oxygens is dependent on the site of substitution in the layer lattice.

17. Thermal decomposition of 14A tobermite from Crestmore. By V. C. Farmer and J. Jeeveratnam, K. S. Speakman and H. F. W. Taylor (University of Aberdeen). (pp. 291-299 of *Symposium on Structure of Portland Cement Paste and Concrete. Spec. Rept. No. 90 U.S. Highway Res. Brd.* 1966).

Tobermorite, a hydrated calcium silicate, is an important constituent of concrete, and has recently been shown to form in soils to which lime has been applied. In this paper infrared spectra, X-ray diffraction patterns and weight-loss curves are used to characterize the several changes in structure which occur on heating the mineral from room temperature to 1000°C.

18. Infrared study of the absorption of benzoic acid and nitrobenzene in montmorillonite. By S. Yariv, J. D. Russell and V. C. Farmer. (*Israel J. Chem.*, **4**, 201-213, 1966).

Humic acid has an acidic, unsaturated, highly condensed organic structure, containing aromatic residues and carboxylic acid groups. Benzoic acid has been selected as a simple analogue of the structure, and its interaction with montmorillonite, an example of the expanding layer silicates commonly found in soil clays, has been investigated. Benzoic acid resembled the neutral but structurally analogous nitrobenzene in that considerable amounts were absorbed in the interlayer space as unionized molecules. Benzoate ion was also found, in amounts which were dependent on the exchangeable cation.

19. Vibrational assignments in nitro-benzene, benzoic acid and other mono-substituted benzenes. By V. C. Farmer. (*Spectrochim. Acta*, **23A**, 728-730, 1967).

Characterization of the surface properties of clays by changes in the vibrational spectra of adsorbed molecules requires a knowledge of the particular vibrations associated with each absorption band. Results relevant to the assignment of absorption bands of nitro-benzene and benzoic acid have been obtained in the course of a study of the interaction of these molecules with montmorillonite.

20. The ecology and physiology of soil fungi involved in the degradation of lignin and aromatic compounds. By D. Jones and V. C. Farmer. (*J. Soil Sci.*, **18**, 74-84, 1967).

The humus fraction of soil, believed to be derived in part from plant lignins, is an important factor in the maintenance of soil structure and fertility. In the present investigations the pellet technique previously developed at the Institute has been employed to isolate, selectively, fungi able to metabolize a lignin preparation extracted from *Phragmites* reed, and aromatic compounds related to lignin. Some of these aromatic compounds have been extracted from soils by other workers and shown to be toxic to plants at very low concentrations. Using U.V. absorption spectrometry it has been shown that up to 40 per cent loss of lignin occurred in pure cultures of certain fungi, and that the related compounds were metabolized completely at the lower concentrations by the majority of the fungi isolated. It is clear from the results that this pellet technique offers many possibilities for studying the localized development of fungi in soil and for isolating, selectively, species concerned in the transformation and degradation of many components of soil organic matter.

21. The wax fraction of soils: separation and determination of some components. By R. I. Morrison and W. Bick. (*J. Sci. Fd Agric.*, **18**, 351-355, 1967).

Because of the great difficulty of resolving the complex mixtures of closely related substances, the chemical nature of the lipid or wax fraction of soil organic matter has received little systematic study, although from time to time small quantities of identified or tentatively identified substances of a lipid nature have been isolated from soils. Recent developments in chromatographic and spectrographic techniques have however greatly reduced the problems of separation and identification, and this paper describes the application of such methods to the study of the wax fractions from a peat and a mineral soil. Long-chain paraffin, methyl ketone, fatty acid and

primary alcohol fractions have been isolated by adsorption chromatography and the individual components of these fractions have been separated and the relative amounts estimated by means of gas-liquid chromatography.

22. The relation between ion absorption and protein synthesis in beet disks. By I. R. MacDonald, J. S. D. Bacon, D. Vaughan and R. J. Ellis (University of Aberdeen). (*J. exp. Bot.*, **17**, 822-837, 1966).

The capability of disks of storage tissue for mineral uptake is similar to that of plant roots. In this study two antibiotics—chloramphenicol and puromycin—both known inhibitors of bacterial protein synthesis, have been used to examine the relationship between protein metabolism and salt absorption in beetroot disks. The results do not support the view that mineral absorption is directly linked with protein synthesis.

23. Development of soluble and insoluble invertase activity in washed storage tissue slices. By D. Vaughan and I. R. MacDonald. (*Pl. Physiol.*, **42**, 456-458, 1967).

Growth of plant cells is accompanied by changes in the activity of certain enzymes, particularly invertase. It has now been demonstrated that in storage tissue slices maintained under aseptic conditions the development of invertase activity occurs in both cell walls and cytoplasm. After two days ageing the proportion of the invertase located in the cell wall was 50 per cent for beet, 60 per cent for potato and 90 per cent for carrot. The high proportion of the enzyme associated with the cell wall might be taken as further evidence for a connection between invertase activity and cell wall growth.

24. The location of chitin in the yeast cell wall. By J. S. D. Bacon, Elizabeth Davidson, D. Jones and Irene F. Taylor. (*Biochem. J.*, **101**, 36C-38C, 1966).

The cell walls of fungi often contain chitin, a nitrogenous polysaccharide, and its decomposition must provide an important source of nitrogen to the soil microflora. Yeast cell walls contain very little chitin, but in the course of further investigations on the enzymic decomposition of yeast and fungal material by soil bacteria it has been discovered that the glucan which accompanies the chitin can be so treated that it dissolves in aqueous alkali. When this is done all that is left of the walls are the "scars" developed at the points where new cells arose by budding. It seems that all the chitin of the wall is located in these structures.

25. The effect of illumination on the malic acid content and anion-cation balance of mustard leaves (*Sinapis alba*). By M. J. Palmer and J. S. D. Bacon. (*Biochem. J.*, **102**, 304-312, 1967).

In continuation of a study of the relationship between organic acids and inorganic nutrition it has been shown that the malic acid content of mustard leaves is influenced by illumination. In a growth room with no natural source of light malic acid was not accumulated unless the plants were given sixteen or more hours of light each day; the malic acid concentration then showed a diurnal rise and fall. Since calcium uptake is closely tied to malic acid accumulation, the calcium content of leaves also depends upon illumination. Some reasons are given for supposing that the effect upon malic acid is primary, the calcium being absorbed subsequently in order to maintain the anion-cation balance.

26. Factors affecting the copper content of oats grown in peat. By M. V. Cheshire, P. C. DeKock and R. H. E. Inkson. (*J. Sci. Fd Agric.*, **18**, 156-160, 1967).

A study of the growth of oats on peat of very low copper content has shown that, although fertilization with calcium, nitrogen and particularly iron greatly improved growth, copper fertilization was essential for proper development. There was only slight evidence for the increased fixation of original peat copper with the addition of nitrogen as nitrate, whereas the adverse effect on growth of nitrogen as ammonia

was striking. Although growth was poor without added copper, it was concluded that the appearance and severity of copper deficiency depended very largely on the major elements contained in the fertilizer amendments.

27. Physiological gradients in the potato tuber. By A. E. S. Macklon and P. C. DeKock. (*Physiol. Plant.*, **20**, 421-429, 1967).

The distribution of the major nutrients, together with citric acid, malic acid and iron, has been studied in potato tubers of the variety Golden Wonder. In immature daughter tubers the constituents studied were evenly distributed along the length of the tuber, but in mature tubers a considerable polarity had developed. The concentrations of potassium, phosphorus and citric acid each increased from the heel to the rose end of the tuber. Iron showed a gradient in the opposite direction. Although the absolute levels of the constituents became reduced, these gradients were maintained in sprouting tubers. In the exhausted mother tubers all these constituents were much depleted and only potassium exhibited any pattern of polar distribution. Malic acid was barely detectable at any stage, and calcium, magnesium, sodium, chloride, sulphate and nitrate were always at low levels and showed no polarity of distribution.

28. Activation of protein synthesis by microsomes from ageing beet disks. By R. J. Ellis (University of Aberdeen) and I. R. MacDonald. (*Pl. Physiol.*, **42**, 1297-1302, 1967).

A unique feature of storage tissue is that when it is sliced and incubated under appropriate conditions, the tissue develops a capacity for ion absorption. The development of this ion absorption capacity has been assumed to be connected with the activation of protein synthesis following slicing. It has now been demonstrated with a cell-free system from storage tissue that there is an activation of protein synthesis at the ribosomal level and that the sensitivity of this system to protein synthesis inhibitors is consistent with results previously obtained using intact slices.

29. Oxygen tension a determining factor in the respiration of potato disks of varying thickness. By I. R. MacDonald. (*Pl. Physiol.*, **42**, 227-232, 1967).

Energy supply is an important parameter to be taken account of when using storage tissue disks in studies of ion absorption. A useful index of energy potential is the respiration rate of the tissues, and in this study it is shown that the respiration rate of potato disks is limited by oxygen availability especially in disks more than 1·0 mm thick.

30. Bacterial infection and ion absorption capacity in beet disks. By I. R. MacDonald. (*Ann. Bot.*, **31**, 163-172, 1967).

The effect of aseptic conditions on mineral absorption by plant roots is currently attracting attention. In this study it is shown that the development of an ion absorption capacity by beet disks is retarded by non-sterile conditions.

31. The role of transmembrane electrical potential in determining the absorption isotherm for chloride in potato. By A. E. S. Macklon and I. R. MacDonald. (*J. exp. Bot.*, **17**, 703-717, 1966).

The influence of potassium and calcium on the absorption of chloride by potato tuber disks at 0°C, which was investigated as part of a study of the mechanisms of ion absorption by higher plants, was explained in terms of a straightforward electrochemical theory of ion transport across cell membranes. Direct measurement of electrical potentials in single cells has confirmed the validity of this theory in describing the uptake of chloride, in the presence of potassium, as a response to electrochemical forces. It has become apparent, however, that in the presence of calcium, forces in addition to the electrochemical ones must determine low temperature chloride uptake.

32. Protozoa in the rhizosphere of *Lolium perenne* L. By J. F. Darbyshire. (*Can. J. Microbiol.*, **12**, 1287-1289, 1966).

It is well established that large populations of bacteria and fungi occur in the rhizosphere region of soil, but protozoa in this region have received scant attention. Estimates of the protozoa (total and cystic) in the rhizosphere and inter-row soil of experimental plots growing S23 perennial ryegrass in 1964 at the Kincardineshire Grassland Experiment Centre of the North of Scotland College of Agriculture are presented in this paper. In July the numbers of flagellate and amoebic cysts (per gram oven-dry soil) in the rhizosphere were significantly larger than in the inter-row soil. The total rhizosphere population of amoebae exceeded the inter-row soil population in August. No rhizosphere effect was detected for ciliates. There were no qualitative differences between rhizosphere and inter-row soil protozoan populations.

33. Protozoa and bacteria in the rhizosphere of *Sinapis alba L.*, *Trifolium repens* L., and *Lolium perenne* L. By J. F. Darbyshire and M. P. Greaves. (*Can. J. Microbiol.*, **13**, 1057-1068, 1967).

Bacteria are well known to be numerous and physiologically active in the rhizosphere soil near plant roots, and there is little information about protozoa in this habitat. This paper deals with the populations of protozoa and bacteria found in the rhizosphere soil in relation to the age of three plants. The largest differences between rhizosphere and unplanted soil populations of protozoa and bacteria were found during the early stages of flowering of both an annual (*Sinapis alba* L.) and a perennial plant (*Trifolium repens* L.). Although the numbers of protozoa were significantly higher in the rhizosphere soils of all three plants than in unplanted soils, the generic composition of the protozoan populations in the two habitats was the same. Desiccation of the soil in which *Lolium perenne* L. was growing caused an initial reduction in the numbers of protozoa and bacteria in the rhizosphere, but not in unplanted soils, and was not correlated with encystment of the protozoa. In all soil samples the numbers of ciliates were low.

34. The hydrolysis of inositol phosphates by *Aerobacter aerogenes*. By M. P. Greaves, G. Anderson and D. M. Webley. (*Biochim. biophys. Acta*, **132**, 412-418, 1967).

Inositol phosphates form the major constituents of the organic phosphorus fraction of soils. It has been shown in previous studies from the Institute that many soil micro-organisms produce the enzyme phytase, which hydrolyses inositol hexaphosphate, releasing inorganic orthophosphate. It is known however that very little hydrolysis of this compound occurs in soil. Consequently an investigation of the factors affecting the hydrolysis of inositol hexaphosphate has been made. In this paper some of the properties of phytase produced by *Aerobacter aerogenes* are described. The products of the hydrolysis were separated, identified and compared with those produced by wheat bran phytase and hydrochloric acid.

35. Lysis of the cell walls of yeast (*Saccharomyces cerevisiae*) by soil fungi. By D. Jones and D. M. Webley. (*Trans. Br. mycol. Soc.*, **50**, 149-154, 1967).

The addition of plant residues to soil results in a considerable increase in activity of fungi, bacteria and actinomyces. This primary stage in the organic matter cycle is followed by a second, during which the initial microbial population becomes moribund and is degraded by yet another microbial population possessing the necessary enzyme systems required to decompose microbial cell components. These components include protein, lipids, etc. and cell-wall complexes; the latter are often of a different chemical composition to plant-cell walls. The present paper describes soil fungi which have the ability to digest cell walls of yeast. Such organisms could well be of importance in the second cycle of organic matter decomposition. Soil micro-organisms causing lysis of microbial structures may also be important in the control of fungal plant pathogens.

36. Estimating optimal nutrient rates for potatoes. By R. H. E. Inkson and J. W. S. Reith. (pp. 377-384 of *Soil Chemistry and Fertility; Trans. jt. Meet. Comm. II & IV. int., Soc. Soil Sci., Aberdeen, 1966*).

A series of 21 4^3 factorial field experiments was carried out over a period of 10 years and measured the effects of nitrogen up to 120 lb N, phosphorus up to 180 lb P_2O_5 and potassium up to 200 lb K_2O per acre on the yields of fresh matter and dry matter. Except where a nutrient did not increase yield, the responses were quadratic in form and a general second degree response surface equation has been used to calculate the optimal economic rates of nitrogen, phosphorus and potassium for individual experiments and for the mean yields for the series. A comparison is made of the yields obtained with optimal rates for individual centres and with the mean optimal nutrient levels. There are large variations in the optimal rates for different centres, and the calculated profit from using the average optimal rates of 85 lb N, 157 lb P_2O_5 and 154 lb K_2O per acre is almost £8 per acre less than that obtained by using the optimal rates for individual centres. The optimal rates, especially for nitrogen and potassium, are usually lower for dry matter than for fresh matter yields, because the percentage of dry matter in the tubers is nearly always decreased by applying moderate to high rates of nitrogen and potassium. On the basis of this work a central composite design, using only 15 treatments, has now been adapted for this type of investigation.

37. Effects of soil magnesium levels and of magnesium dressings on crop yields and composition. By J. W. S. Reith. (pp. 97-109 of *Soil Potassium and Magnesium. Tech. Bull. Minist. Agric. Fish. Fd.*, No. 14. H.M.S.O. 1967).

Field experiments have been undertaken on soils with a relatively low magnesium status to measure the effect of applying this nutrient on the yield and magnesium content of herbage and crops and on the readily soluble content in soils. A range of supplements, including magnesian limestone and calcined magnesite, have been used. An assessment has been made of the magnesium status of soils in northern Scotland. So far there is no evidence that this nutrient needs to be specially applied to meet the growth requirement of the common agricultural crops. Quite large dressings of magnesium are needed to produce an appreciable increase in the percentage in herbage. Some results are presented showing the effects of nitrogen and potassium dressings on the magnesium contents of herbage and crops. The relationships between the percentage in red clover and the soil content is considered for five soil types. For slightly acid mineral soils a tentative minimum value is suggested for the readily soluble magnesium level required to ensure that the percentage in herbage is as high as possible under practical conditions.

38. The intensity and quantity aspects of soil phosphate status and laboratory extraction values. By E. G. Williams. (*An. Edafol. Agrobiol.*, **26**, 525-546, 1967).

The quantity, intensity, mobility and capacity aspects of soil P status are briefly reviewed in relation to crop criteria and the characteristics of P extraction methods. The implications of the quantity and intensity factors are experimentally assessed from laboratory and pot studies on the crop correlations and inter-relationships of a selection of contrasting P values for a range of 40 acid soils. The results emphasize the higher intensity dependence of yield compared with P uptake. They also illustrate how conventional mild extractants give composite quantity-intensity indices, and confirm that their success depends mainly on avoidance of attack on unavailable P coupled with reflection of intensity by variation from soil to soil in the partition of soluble P between the soil and the extract. Several features also demonstrate the fundamental importance of degree of P saturation in relation to P status.

39. Nucleic acids, derivatives, and organic phosphates. By G. Anderson. (Chap. 3 of *Soil Biochemistry*. Edited by A. D. McLaren and G. H. Peterson. New York: Dekker. 1967).

Soil organic matter contains a small but fairly uniform proportion of phosphate, the nature of which has been the subject of many investigations, particularly in areas where there is a lack of phosphate readily available to plants. The compounds so far identified belong to, or are derived from, three classes of phosphate esters which occur widely in nature, namely the nucleic acids, the inositol phosphates and the phospholipids. In this review article details are given of some of the properties of these compounds and of the methods which have been used to identify and measure them in soils.

(B) *Awaiting Publication at 30th September, 1967—*

40. Heavy minerals. By W. A. Mitchell. (To appear in *Encyclopedia of Soil Science*. Edited by J. E. Gieseking. Vol. 2, Section D. Berlin: Springer).

41. The classification of soil silicates and oxides. By R. C. Mackenzie. (To appear in *Encyclopedia of Soil Science*. Edited by J. E. Gieseking. Vol. 2, Section D. Berlin: Springer).

42. The calcium oxalate content of some lichens growing on limestones. By J. K. Syers (Lincoln College, Canterbury, New Zealand) and A. C. Birnie and B. D. Mitchell. (*The Lichenologist*, 3, 409-414, 1967).

43. Interactions between organic substances and inorganic diluents in differential thermal analysis. By S. Yariv, A. C. Birnie, V. C. Farmer and B. D. Mitchell. *Chemy Ind.*, 1967, 1744-1745).

44. Instrumentation. By R. C. Mackenzie and B. D. Mitchell. (To appear as Chap. 3 of *Differential Thermal Analysis*. Edited by R. C. Mackenzie. London: Academic Press).

45. Mineralogical and chemical characteristics of a gley soil from north-east Scotland. By B. D. Mitchell, J. M. Bracewell, A. S. de Endredy, W. J. McHardy and B. F. L. Smith. (Submitted to *Trans. IX int. Congr. Soil Sci., Adelaide, Australia*).

46. Oxides and hydrous oxides of silica. By B. D. Mitchell. (To appear in *Encyclopedia of Soil Science*. Edited by J. E. Gieseking. Vol. 2, Section D. Berlin: Springer).

47. The oxides of iron, aluminium and manganese. By R. C. Mackenzie, E. A. C. Follett and R. Meldau (Gütersloh, Germany). (To appear in *The Electronoptical Investigation of Clays*. Edited by J. A. Gard. London: Mineralogical Society).

48. The clay mineralogy of some soils derived from a biotite-rich quartz gabbro in the Strathdon area, Aberdeenshire. By M. J. Wilson. (*Clay Minerals*, 7, 91-100, 1967)

49. Saponite from the Dalradian meta-limestones of north-east Scotland. By M. J. Wilson, D. C. Bain and W. A. Mitchell. (Submitted to *Clay Minerals*).

50. Soils of the country round Haddington and Eyemouth. (Sheets 33, 34 and 41). By J. M. Ragg and D. W. Futty. (To appear as *Mem. Soil Surv. Gt. Br.*).

51. A natural system of soil classification. By J. W. Muir. (Submitted to *J. Soil Sci.*).

52. Land use capability survey. By J. S. Bibby. (Submitted to *Reclamation*: an occasional publication of the *Scottish Peat and Land Development Association*).

53. Trace elements in soils. By R. L. Mitchell. (Submitted to *Proc. N.A.A.S. Conf. on Trace Elements in Soils and Crops, London, 1966*).

54. A display microphotometer for use in the analysis of soils and related materials.

By R. L. Mitchell, R. O. Scott and A. M. Ure. (*XIII Colloq. Spectrosc. intern., Ottawa*, 1967, 324-338, 1968).

55. The determination of cobalt in soil extracts by atomic absorption: a study of interference effects. By A. M. Ure and R. L. Mitchell. (*Spectrochim. Acta*, **23B**, 79-96, 1967).

56. Hydroxyl vibrations in layer silicates. By V. C. Farmer, J. D. Russell, J. L. Ahlrichs and B. Velde (Sorbonne University, Paris, France). (Submitted to *Bull. Grpe franc. Argiles*).

57. The characterization of soil minerals by infrared spectroscopy. By V. C. Farmer and F. Palmieri. (To appear in *Encyclopedia of Soil Science*. Edited by J. E. Giesseking. Vol. 2, Section D. Berlin: Springer).

58. Characterization of clay minerals by infrared spectroscopy. By V. C. Farmer, J. D. Russell and J. L. Ahlrichs. (Submitted to *Trans. IX int. Congr. Soil Sci., Adelaide, Australia*).

59. Lysis of cell walls of *Mucon ramannianus* Möller by a soil *Streptomyces* sp. By D. Jones, J. S. D. Bacon, V. C. Farmer and D. M. Webley. (Submitted to *Antonie van Leeuwenhoek*).

60. The chemical environment of soil bacteria. By J. S. D. Bacon. (pp. 25-43 of *The Ecology of Soil Bacteria*. Edited by T. R. G. Gray. Liverpool University Press, 1967).

61. Soil lipids. By R. I. Morrison. (To appear as Chap. 19 of *Organic Geochemistry: Methods and Results*. Edited by G. Eglinton and Mary T. J. Murphy. Berlin: Springer).

62. The effect of inhibitors on the increase in invertase activity and RNA content of beet disks during ageing. By D. Vaughan and I. R. MacDonald. (*J. exp. Bot.*, **18**, 587-593, 1967).

63. Invertase development in storage tissue disks of *Beta vulgaris*: its nature, extent and location. By D. Vaughan and I. R. MacDonald. (*J. exp. Bot.*, **18**, 578-586, 1967).

64. Effect of humic acid on the development of invertase activity in slices of beetroot tissue washed under aseptic conditions. By D. Vaughan. (Submitted to *Proc. Symp. Humus et Planta, IV, Prague*, 1967).

65. Uptake of nitrogen by plants. By P. C. DeKock and E. A. Kirkby. (Submitted to *Proc. N.A.A.S. Conf. on Nitrogen and Soil Organic Matter, London, 1964*).

66. The metabolism of nitrogen in plants. By P. C. DeKock. (Submitted to *Proc. N.A.A.S. Conf. on Nitrogen and Soil Organic Matter, London, 1964*).

67. Fundamental aspects of iron nutrition of plants. By P. C. DeKock. (Submitted to *Proc. N.A.A.S. Conf. on Trace Elements in Soils and Crops, London, 1966.*)

68. An investigation into the effect of varied phosphorus and iron concentrations in the nutrient medium on the cation and anion content of oats. By Linna Bentley (University of London), P. C. DeKock and R. H. E. Inkson. (Submitted to *Pl. Soil*).

69. An electron microscope study of the fine structure of *Acremoniella* sp. By D. Jones. (Submitted to *Trans. Br. mycol. Soc.*).

70. Examination of mycological specimens in the scanning electron microscope. By D. Jones. (*Trans. Br. mycol. Soc.*, **50**, 690-691, 1967).

71. Surface features of fungal spores as revealed in a scanning electron microscope. By D. Jones. (Submitted to *Trans. Br. mycol. Soc.*).

72. A new enrichment technique for studying lysis of fungal cell walls in soil. By D. Jones and D. M. Webley. (Submitted to *Pl. Soil*).

73. Techniques for the study of localized microbial activity in soil. By D. M. Webley and D. Jones. (Submitted to *Trans. IX int. Congr. Soil Sci., Adelaide, Australia*).

74. Effects of magnesium dressings on soils and crops. By J. W. S. Reith. *Trans. VIII int. Congr. Soil Sci., Bucharest*, 1964, **4**, 337-345, 1967).

75. Copper deficiency in crops in north-east Scotland. By J. W. S. Reith. (*J. agric. Sci.*, **70**, 39-45, 1968).

76. Other organic phosphorus compounds. By G. Anderson. (To appear in *Encyclopedia of Soil Science*. Edited by J. E. Gieseking. Vol. 2, Section C. Berlin: Springer).

77. Sulphur in soil organic substances. By G. Anderson. (To appear in *Encyclopedia of Soil Science*. Edited by J. E. Gieseking. Vol. 2, Section C. Berlin: Springer).

78. Observations on the accuracy of an ignition and an extraction method for measuring organic phosphates in some Canadian soils. By R. B. McKercher and G. Anderson. (Submitted to *Soil Sci.*).

79. Content of inositol penta- and hexaphosphates in some Canadian soils. By R. B. McKercher and G. Anderson. (Submitted to *J. Soil Sci.*).

80. Investigations on the analysis of inositol hexaphosphate in soils. By G. Anderson. (*Trans. VIII int. Congr. Soil Sci., Bucharest*, 1964, **4**, 563-572, 1967).

(C) *Papers by Members of Staff on Leave of Absence: Published or Accepted for Publication—* (*No reprints*).

81. Soil survey of part of the Taieri Uplands, Otago, New Zealand. By J. M. Ragg and R. B. Miller (New Zealand Soil Bureau). (To appear as *Rept. N.Z. Soil Bureau*).

82. The absorption of 3-aminotriazole by montmorillonite. By J. D. Russell and M. I. Cruz and J. L. White (Purdue University, Indiana, U.S.A.). (Submitted to *J. agric. Fd Chem.*).

83. Humic acid II. Structure of humic acids. By M. V. Cheshire and P. A. Cranwell, C. P. Falshaw, A. J. Floyd and R. D. Haworth (Sheffield University). (*Tetrahedron*, **23**, 1669-1682, 1967).

(D) *Theses—*

The following theses have been accepted for the degree of Ph.D. by the University of Aberdeen.

3-*Amino*-1, 2, 4-*triazole-induced chloris in* Lemna minor *L.* By Mrs Alison M. Innes.

Scottish woodland history since Boreal time as revealed by pollen analysis of peat. By S. E. Durno.

Studies on the sulphur relationships of selected Scottish soils. By N. M. Scott.