THE MACAULAY INSTITUTE FOR SOIL RESEARCH

1946-1947

ANNUAL REPORT

The Macaulay Institute is situated in Countesswells Road, about three miles from the centre of the town. Buses run at frequent intervals from Union Street to the Seafield terminus (Route 18) which is within 10 minutes walk of the Institute

THE MACAULAY INSTITUTE FOR SOIL RESEARCH

CRAIGIEBUCKLER, ABERDEEN

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CONTENTS

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THE Council of Management of The Macaulay Institute for Soil Research regret that it has still not been possible to proceed with the building of extensions and, that, in order to relieve acute congestion in the laboratories, it was necessary to resort to internal re-allocation of space and the use of surplus huts. The Council, however, has made the necessary plans for the erection of new permanent buildings and the utilization of the present fabric as soon as conditions permit.

Many applications from overseas to carry out post-graduate studies within the Institute had to be declined temporarily, but at the request of the Colonial Office several workers have spent varying periods at the Institute.

It has been, however, possible to inaugurate the scheme for training spectrographic workers and it is hoped that the spectrographic laboratories to be established in close association with the Institute will soon be opened at the East and West of Scotland Colleges of Agriculture.

Fundamental geochemical investigations of Scottish rocks and parent materials are contemplated, with particular reference to trace elements, and to the development of the past co-operative work with the sister Institutes dealing with Animal Diseases and Animal Nutrition.

At the request of the Forestry Commission, the Council has agreed to train a specialist in forest soils who will investigate the physico-chemical relationships of soils upon which canopy is being formed.

The investigation of the physical chemistry, the X-ray structure and the mineralogical composition of clays has been undertaken by a team which forms the nucleus of a pedological department.

A study of the changes which occur in soil organic matter has been started by a team of organic chemists and microbiologists.

The Agricultural Research Council has established a Soil Survey Research Board and the Director of the Institute has accepted nomination as one of the members of the Board. The new Board will supervise the work of soil survey in Britain and the Council feel gratified that the Soil Survey of Scotland will continue to be based upon The Macaulay Institute.

In pursuance of the past policy governing the maintenance of soil fertility, it has now been possible to use the results of soil surveys as a basis for the selection of field experiment areas with a view to subsequent correlation of cropping performances with soil type. Associated with these activities a new plant physiological chemistry section has been formed and work upon the soil-plant relationships has been started.

The Institute has continued to be represented on the Agricultural Research Council Conferences on

(*a*) methods of fertilizer application to agricultural and horticultural crops.

(*b*) mineral deficiencies in agricultural and horticultural crops.
(*c*) land drainage.

and on Advisory Committees on

(*a*) Soils Sub-Committee of Committee for Colonial Agricultural, Animal Health and Forestry Research.
(*b*) Sub-Committee on Nutritional Problems in Tree Nurseries (Forestry Commission).

The Council of Management tenders thanks to the Agricultural Research Council and the Department of Agriculture for Scotland for grants received, to the Forestry Commission for grants in aid of training a forest soil specialist and forest advisory services, to the Carnegie Trust for a quinquennial grant and to other benefactors.

September, 1947.

SOIL FERTILITY

Soil Fertility Investigations

With the ultimate objectives of improving the technique for assessing the nutrient status of soils and of defining the measures to be adopted in the maintenance and improvement of soil productivity, field, pot and laboratory experimental work has been continued on the general lines detailed in previous years' reports. Field experiments are in progress at about forty centres which were selected on the basis of soil survey information as representative of particular soil associates, and appropriate supplementary information is being obtained by laboratory examination of samples of soil and produce from the experiment areas. By these means it is possible to obtain useful information on the manurial and other requirements of individual soils and, at the same time, to investigate the influence of pedological factors on soil productivity.

General Manurial and Liming Experiments. These cover the investigation of the effects of lime and fertilizers on the yield and composition of different crops on a range of soils. They include studies on the interaction effects of nitrogen, phosphate and potash, the nutritional requirements of individual crops, and the rotational manuring likely to be most suitable for different types of soil. As indicated in previous reports, experiments are also being conducted to compare the values of such different liming materials as burnt calcium and magnesian limes, limestones of varying degrees of fineness, magnesian limestone, paper works lime, shell sand and a falling haematite slag. Further yield data for barley and hay support the preliminary conclusion that differences between the various materials are small relative to the over-all effect of liming which, especially with the more sensitive crops, is marked on most acid soils.

Phosphate Relationships of Soils. Investigations on various aspects of this subject have been continued along the lines defined in last year's report.

On the field experiment side progress has been made in establishing an essential background of basic information on the responses to and degree of utilization of phosphate by different crops on different soils. Further experiments have been carried out on the interaction of lime and phosphate and on the efficacy of different measures intended to reduce fixation and increase the efficiency of applied phosphate. One obvious approach to the latter problem is to modify the chemical and physical form in which phosphate is applied, and with this in view experiments with different phosphates in granular and powdered forms have been carried out during the past few years. The results of these experiments, which have now been submitted for publication,[17] are briefly as follows.

On the acid soils occurring in the north-east of Scotland it appears that variations in effectiveness between different forms of phosphate are generally small and relatively unimportant, when considered in relation to the widespread need for phosphate and the large responses commonly obtained. The materials tested covered the wide solubility range from mineral phosphates to superphosphate and the only notable difference is provided by

the consistently low effectiveness of mineral phosphates on potatoes. Superphosphate has invariably shown up very well. Nevertheless, too much emphasis appears to have been placed on water-solubility as a criterion of manurial value, for which the citric acid test also provides a very useful criterion. The general form of the response curves obtained indicates that, as a rule, there is little further response from dressings higher than about 100 lb. P_2O_5 per acre, even with responsive crops on deficient soils. Since the residual effects are generally very small it would appear that dressings considerably in excess of this amount are uneconomical. In the present state of knowledge frequent applications of phosphate in accordance with the responsiveness of individual crops, coupled with suitable placement and adequate liming, seems to be a very sound practice to adopt. It is also of interest to note that, so far, no evidence has been obtained to support the view that granulation, particularly of water-soluble forms, increases the efficiency of phosphates. Further evidence is required, however, from experiments with granules covering a wider range of particle size than has hitherto been available, and work on this problem is in progress.

Pot experiments of the Mitscherlich type have also been found to give useful indications of the effectiveness of different phosphates, particularly when comparisons are made in soil-sand media with P_2O_5 addition of 0·1 to 0·2 g. per pot. It appears safe to predict that a phosphate effective on oats in pots under these conditions will be equally effective on other crops in the field, but the converse is not always true. Pot comparisons with sand alone show greater differences between phosphates than are obtained in soil-sand media, and these in turn tend to be more sensitive than field experiments. This is probably due to the obscuring effect of the native phosphate in the soil and the intervention of phosphate fixation. The main objectives in the pot experiments in progress are the investigation of the interaction of lime and phosphate and the basic characterization of different soil types. Laboratory work on these and other special aspects of the phosphate relationships of soils has also been continued, particularly on the role of calcium and the replacement of phosphate by various anions, especially fluoride ions.

Fertilizer Placement. In previous reports reference has been made to the study of the effects on germination, growth, yield and composition of crops of different methods of applying fertilizers. A report on the results of the 1946 experiments has been submitted to the Agricultural Research Council, who have again given a grant in aid of further work on the subject. A summary account of work on the placement of mineral nutrients in soils has also been given in a paper to the XIth International Congress of Pure and Applied Chemistry.[18] From the more recent experimental work, the following further conclusions may be drawn :

Cereals :

(*a*) In combine drilling of nitrogen there does not appear to be any direct advantage at all comparable with the benefit to be derived from combine drilling phosphate. There is, however, a possible saving in labour, and experimental results indicate that dressings up to 1½ cwt. per acre sulphate of ammonia and up to 2 cwt. per acre nitro chalk may be safely drilled with the seed.

(*b*) There are no outstanding differences in grain yields from broadcast and drill applications of N P fertilizers, but combine drilling of these may increase the proportion of straw to grain.

(*c*) Until more information is available it appears inadvisable to combine drill N P K mixtures at rates supplying the equivalent of more than about 25 lb. N and 45 lb. K_2O per acre.

Direct Reseeding :

(*a*) Combine drilling of phosphate with grass and clover seeds is likely to be at least equal and in most cases superior to applying the phosphate broadcast.

(*b*) Broadcast application of sulphate of ammonia and nitro chalk has proved superior to combine drilling these nitrogenous compounds with the seeds mixture.

(*c*) With N P and N P K fertilizer mixtures at rates up to 6 cwt. per acre there does not appear to be any difference between broadcast and drill applications.

Roots :

In preliminary experiments on turnips and swedes placement of superphosphate about 1 inch below the seed proved superior to broadcast application.

During 1947 experiments have been continued to study (1) the effect of the method of applying nitrogen on the response to broadcast and drill applications of phosphate, and (2) the effect of drilling potash at varying rates alone and in combination with nitrogen and phosphate. A series of experiments has also been commenced to compare the effects of broadcasting and placing fertilizers on roots.

Forest Nursery Investigations. Co-operative work with the Research Branch of the Forestry Commission on various aspects of the nutrition of forest tree seedlings has been continued on the lines indicated in previous reports. Some of the results obtained in this work have been given in a paper dealing with the "Maintenance of Fertility in Forest Nurseries" which was read at the recent meeting of the British Association in Dundee.

At the request of the Soil Sub-Committee of the Committee for Colonial Agricultural, Animal Health and Forestry Research a memorandum on "Planning and Conduct of Fertilizer Experiments" has been prepared.[8]

Advisory Work

During the year field and laboratory examination of soils for advisory purposes has been continued. Analyses have been carried out on over 5,000 samples of soil, and advice has been given on the treatment likely to be most suitable for the areas sampled. Most of these samples have been drawn from ordinary agricultural land, but soils from horticultural land, forest nurseries and sports grounds have also been examined. In addition, numerous analyses have been made on limestones, calcareous sands, wood ashes, composts and other materials likely to be of value in the improvement of soil productivity.

Recording of the analytical data for advisory soil samples has been continued with the soils being grouped as satisfactory, slightly low, or low in relation to the needs of an ordinary rotation of crops. The results, which are indicative of the general nutrient status of the soils of the area, are in close agreement with those of previous years. For instance, of over 4,000 samples of soil from Aberdeenshire which have been examined during the past few years, only 2 per cent. have satisfactory lime contents, while 50 per cent. are slightly low and 48 per cent. are either low or very low in lime. Deficiency in phosphate is also very widespread with 52 per cent. of the samples falling into the low or very low and 42 per cent. into the slightly low categories. Potash deficiency is relatively less widespread, the percentages in the various groups being 14 per cent. satisfactory, 73 per cent. slightly low and 13 per cent. low or very low.

In the 1945–46 report reference was made to the grouping of advisory soils from Aberdeenshire in terms of the soil associates which had been identified in a reconnaissance soil survey on the scale of 2·5 inches to 1 mile. Except for one or two of the more extensively occurring associates, the numbers of soils from the different associations are still too small to permit of definite conclusions being drawn. As might be expected, lime deficiency appears to be slightly less widespread on soils derived from basic igneous and texturally heavy Old Red Sandstone parent materials. Phosphate deficiency is also less pronounced on soils of basic igneous origin, while potash deficiency is relatively most widespread on these and on soils derived from granitic boulder clays and from water sorted sediments.

Soil Drainage Water

Measurement of rainfall and drainage flow from the Craibstone Lysimeters, which are now under pasture, has been carried out as usual during the year 1st October, 1946 to 30th September, 1947. Rainfall, including snow, totalled 37·13 inches, of which from 42 to 49 per cent. appeared as drainage.

SOIL SURVEY AND PEDOLOGY

Soil Survey

Kincardineshire.—The reconnaissance survey of Kincardineshire on a scale of 2·5 inches to 1 mile has been continued into the area south of the River Dee and west to the county boundary as far as a line running from Crawton through Strathfinella Hill to the boundary. An area of approximately 180 sq. miles, of which about one-half is hill land under heath, moor and forest, has been mapped by one survey party. The soils fit in part into three previously established soil associations, (1) Countesswells, (2) Foudland and (3) Corby, and three new associations have been established, (4) Stonehaven, (5) Laurencekirk and (6) Ury.

1. *Countesswells Association.* This association developed on granitic and gneissic boulder clay, extends south from the Dee valley to approximately the Cowie water and west through extensive areas of heath and moor hill land to the county boundary. The area of agricultural land extending from the Dee inland for a distance of approximately 4 miles is smoothly rolling at an elevation of from 100 to 450 ft. The uncultivated land is hilly to mountainous (450–2,500 ft.) as can be readily seen from the Cairn o' Mount road which crossses the area. The soils of this hill country are typically those of the mor- and peaty- podzol zone. On convex slopes, dominantly heather covered, podzols are common with an A_1 horizon of 6–9 inches of calluna mor and an A_2 of 4–6 inches with a strong iron pan underlying the A_2 horizon ; on concave slopes, and areas of gentler gradient under calluna nardus or calluna scirpus with lesser or greater amounts of molinia or cotton grass, podzols occur with a freely drained C horizon but with a strong iron pan, often at considerable depth (24 inches). The deep bleached, former A_2 horizon and possibly the B may be very wet, thus forming a surface gley in which drainage waters pass laterally through the soil above the pan. True gley soils are relatively scarce in this area due to unfavourable topographic features. Normal podzols without an iron pan sometimes occur on covex slopes under Scots pine plantations. The texture of the soils is light being generally a gravelly, loamy coarse sand, but may approximate to a gritty, sandy loam. Stones and boulders are common throughout this association.

Elevations over 1,000 ft. on steeply sloping ground are frequently covered with hill peat varying in thickness from 3–6 ft., while at low altitudes peat may also be found on moderately sloping ground with a northern exposure where the vegetation is mainly cotton grass occurring in tussocks. An iron pan is invariably found beneath what appears to be a gleyed A_2 horizon, and the C horizon often is a yellowish-brown freely drained glacial till.

The soils of the arable areas are dark brown to dark grey-brown, gritty, sandy loams to loamy sands. On the convex slopes where the soils are originally derived from the podzol with iron pan, the cultivated surface soil sometimes incorporates the iron pan and part of the B horizon. Very frequently, however, the pan may still be found at some depth under the plough layer. Particularly on the higher slopes where the standard of farming has been poor, it is thought the pan, once disturbed, may re-form

at a lower depth. In the Netherley district considerable areas of flatter ground occur. These have soils of the poorly drained, true gley type, and the less poorly drained areas comprise soils of the podzol type with a deep pan.

2. *Foudland Association.* This association developed on boulder clay derived from slates, metamorphosed argillaceous rocks and schistose grits, extends in a belt of some 2 miles in width, running in a south-west—north-east direction from north-west of Stonehaven to Cairn o' Mount and the Clattering Bridge. Its occurrence is related to the southern slopes of the extensive area of hill ground lying to the north of it. A considerable part of this area consists of one large south-facing slope, the higher elevations of which are heather moor. Its altitudinal range is from 250–1,500 ft.

The soils of this area and its features in general are those found elsewhere for this association—namely, a broadly rolling to hilly topography, an absence of stone dykes, and large fields, free from stones of a size large enough to interfere with cultivation. The dominant soil is a freely drained podzol and when cultivated has an A horizon varying in depth from 7–10 inches and of a greyish dark brown colour. It is very smooth when handled and in texture is a silty, fine sandy loam. The B horizon is mellow and soft, yellow-orange in colour, 6–8 inches thick, and overlies the C horizon—a greyish-yellow, fine sandy loam with a moderate to high content of slaty chips.

The poorly drained soils (true gleys) are confined to depressions found towards the summits of the hills and at the foot of the slopes where the topography is comparatively flat.

3. *Corby Association.* This association is developed on gravel but is not extensive. It occurs on morainic mounds, frequently continuous but sometimes isolated, stretching southward from Aberdeen parallel to the coast and extending inland for about 1 mile. It may best be seen east and south of Loirston Loch where the topography is morainic knob and kettle. Features of the area are uneven to rough topography, small fields and crofts, stone dykes of considerable thickness and a generally poor quality of farm land and standard of farming.

The soils are variable over short distances; texturally they are light, being stony, loamy sands of a very dark brown colour. The uncultivated soils on the sloping sites are strong podzols with a thin iron pan underlying the A_2 horizon which is of 3–6 inches thickness. On the flatter sites and even in depressions formerly filled with peat but now cut over, the remaining 12 inches of peat overlies an organic stained, greyish, stony, loamy sand, which passes at the base into a bluish-grey loam. An iron pan underlies this latter layer and may be at a depth of 20–36 inches. Under the pan the yellowish to natural coloured gravel looks freely drained in appearance but is completely sealed off from the present soil-forming processes. Originally it appears to have been the B and C layers of a podzol.

Numerous gravel mounds, consisting mainly of conglomerate rocks of Old Red Sandstone origin together with andesitic lava, occur in the area to the south-west of Stonehaven towards Laurencekirk. While these are morainic deposits and have been provisionally mapped as Corby, the presence of the basic lava rocks may necessitate the grouping of these soils into a new association, possibly due to their higher base status.

4. *Stonehaven Association.* This is a new association related to the Cruden Association (*Ann. Rep.*, 1942–43, p. 17) in its geological origin of reddish-brown, clay loam boulder clay, but differing from it by the presence of a high content of andesitic lava rocks and conglomerate pebbles. It extends south-west from Stonehaven, bounded on the west by the Foudland Association and in the south by the Laurencekirk Association (see below). Topographically the association is smoothly rolling to rolling ; the summits tend to be considerably stonier and lighter in texture than the smoother slopes and lower flats, being stony sandy loam as compared with clay loam.

Much of the soil of this area, predominantly arable, is of a slightly poorly drained type. The profile may be described as follows :

A Horizon . .	medium brown loam, with slightly reddish tint.
B–G Horizon . .	brown, reddish loam to clay loam; cloddy, with yellow ochreous mottling.
C Horizon . .	brownish-red clay to clay loam boulder clay; ochreous mottling.

The steep slopes of the uncultivated hills, e.g. Strathfinella are podzols, with 4–8 inches of calluna mor A horizon and sometimes a weak iron pan beneath the A_2 horizon.

The area is good to very good agricultural land and the farms are large to medium in size.

5. *Laurencekirk Association.* Only the northern fringe of this association has been encountered during this year's survey work. The surface layers consist of red to brownish-red, clay loams and clays overlying red clay glacial till with possibly some lacustrine deposits. The stone content is low. With its smooth topography the Association closely resembles the Cruden Association, except that the surface horizon is of a brighter red colour. The northern limit of this association is in the vicinity of Glenbervie and may be observed extending through the flatter low ground to and beyond Laurencekirk. The soils are mainly poorly drained.

6. *Ury Association.* This association consists of a small area of mixed drift composed of granite, metamorphosed slaty rocks, quartz grit, Old Red Sandstone conglomerate, sandstones and lava rocks, in various proportions. It occurs to the north-west and north of the Ury Estate, Stonehaven, and gives rise to freely drained soils of loam texture on loam drift parent material.

Detailed Survey. Soil maps and reports were prepared of four farms in central Scotland which were being considered as possible sites for soft-fruit and horticultural research stations. The soils of these areas on carboniferous till, Old Red Sandstone till, and alluvium, did not fit any previously established associations.

During the year a number of visitors from overseas were shown many of the soil types of north-east Scotland. Three Officers about to take up duty in the Colonies, spent varying periods on the survey, while a British Council scholar from Chile also studied the technique of soil survey.

Laboratory Investigations

Routine analyses have been completed on forty soil profiles representative of the main hydrologic associates of the soil associations mapped in the previous year. Particular attention has been given to ascertaining trends

in the distribution of certain constituents in these hydrologic sequences of soils. It is apparent that the distribution of organic matter, total phosphate and phosphate soluble in 2·5 per cent. acetic acid, *p*H, exchangeable calcium and magnesium, and amorphous sesquioxides, is correlated with the degree of natural drainage of the soil and with the parent material.

A paper on some modifications of the hydrometer method for mechanical analysis is in preparation.[22] A communication on the variation in the phosphate content of naturally freely drained and poorly drained soils was published.[4] A report on the colorimetric method for determining aluminium in soils is nearing completion [23] and a paper [19] dealing with the association concept and the soils of north-east Scotland has been submitted for publication.

Soil Geology

Galloway. A reconnaissance survey, combined with soil sampling, was made of certain areas of Kirkcudbrightshire in connection with the incidence of a pining condition in sheep, caused by cobalt deficiency. A series of traverses was made across the affected areas in an attempt to correlate the incidence of the disease with the type of soil parent material and soil association. The soils of the areas seen so far can be grouped on the following basis: residual soils on igneous rocks (granite, granodiorite, etc); soils on glacial drifts mainly derived from these igneous rocks; residual soils on sedimentary rocks (shale, grit, greywacke); soils on glacial drifts mainly derived from these sedimentary rocks; soils on glacial drifts of mixed rock origin, both sedimentary and igneous rocks being involved. The incidence of the disease appears to vary according to the type of soil parent material and so far has been found to be most intense in the igneous rock areas or in the areas where the glacial drift is largely derived from these igneous rocks. This survey is being continued.

Central Scotland. The glacial drifts and alluvial deposits forming the soil parent materials on the four farms surveyed in connection with the Horticultural Research Centres project were differentiated, and detailed soil maps on a scale of 6 inches to 1 mile prepared.

Aberdeenshire and Kincardineshire. Various areas of Aberdeenshire and Kincardineshire were visited in connection with the soil surveys of these counties and soil parent materials examined to determine the soil associations.

Visits were also paid to various centres in these counties in connection with the location of field experiments.

The mineralogical study of the fine sand fractions of soils and their parent materials obtained during the soil survey of Aberdeenshire and also of soils from areas underlain by rocks of the Old Red Sandstone formation was continued. These parent materials are glacial drifts and because of the complex nature of the underlying rocks the drifts are of mixed lithological composition. The determination of the mineral composition of the matrix of the drifts serves to characterize them and provides a basis for delineating the soil associations. A paper is in preparation discussing the results of an investigation of the mineralogical composition of the soils and their parent materials in northern Aberdeenshire.[25]

A variety of materials was examined in connection with the advisory service provided by the Institute.

Composition of Clay Minerals

X-ray Analysis. Weathered flakes of biotite from the coarse fractions of the soils of the Insch Association give diffraction patterns very similar to those obtained from a micaceous mineral occurring in the clay fractions. In order to throw more light on the nature of the clay mineral, the weathering of biotite has been studied and four stages in the decomposition of this mineral have been isolated from the sand fractions of the soils.

The change in the biotite effected by the process of weathering as traced by the X-ray diffraction method is essentially an increase in the unit cell height, the *a*- and *b*- dimensions of the unit cell remaining almost unaltered. Differential weathering taking place along cracks and cleavage planes causes some layers (or parts of layers) of the biotite structure to expand along the *c*-direction while others are still in the non-expanded condition. As a result a mixed layer mineral is produced as a temporary stage in the weathering. Ultimately all the layers expand and produce a structure very similar to, but not identical with that of vermiculite. Chemical analyses, moreover, show that magnesia is lost from the biotite lattice on weathering and not concentrated as in true vermiculite. Optical measurements too differ from those of vermiculite. Under the microscope the process of weathering is represented by a progressive blurring of the interference figure and a progressive reduction in the refractive indices.

Marked colour changes are associated with the decomposition of the biotite, which from glistening black in the fresh condition passes through brown and golden yellow to pale yellow. At this stage the mineral loses some of its lustre and again takes on a brownish tinge. The colour change from brown to golden yellow appears to be associated with the phenomenon of exfoliation since the colour change can be artificially produced in this way. No variation in optical properties or structures takes place during exfoliation which suggests that the phenomenon is merely a mechanical prising apart of the structural layers. All the decomposed biotite flakes occurring in the soil profiles appear to have been already partly exfoliated by natural processes.

The base exchange capacity of the mineral increases as the weathering proceeds. It is rather interesting in this connection that, when the base exchange capacity of a sample of vermiculite was tested, a very high value (c. 100 m.e. per 100 g.) was obtained, indicating that vermiculite has a base exchange capacity of the order of that obtained from the montmorillonites.

Although at first sight the weathered biotite crystals seemed to give the same type of powder pattern as the micaceous clay mineral, further investigation revealed a number of essential differences. These differences are interpreted to mean that the micaceous mineral of the soil clays, which like biotite is an octophyllite, is not derived directly from the breakdown of the biotite crystals in the parent rock but is a secondary product. This interpretation obviates the necessity of explaining how a mineral (biotite), which is a minor constituent of the parent Insch rocks, could be concentrated sufficiently to become a major constituent of the soil clays derived from these rocks.

The weathering of this secondary biotite in the soil clays closely parallels the process traced in the primary macroscopic biotites. In the clays of the freely drained associate, a vermiculite-like end-member is produced and

intermediate stages are represented by mixed layer biotitic-vermiculite structures. In the only poorly drained profile examined so far, the mineral shows a tendency to develop a freely expanding lattice such as occurs in the montmorillonites, although the non-basal reflections of the mineral are unchanged. The heptaphyllite variety of illite also occurs in the lower layers of this profile.

Apart from the micaceous mineral, the other main crystalline constituent of the Insch soil clays is a kaolinitic member (usually halloysite). The kaolinitic mineral normally becomes more prominent in the upper (more highly weathered) layers of the profiles, suggesting that it may be derived at least partly from the breakdown of the micaceous clay mineral.

Provisional results indicate that, away from the basic igneous area of the Insch Association, heptaphyllite illite becomes of importance as a soil clay constituent but the octophyllite mineral is still present in many cases although in reduced quantity. Only at one of the localities so far examined, viz. at Ordley, where the parent material is till derived from mixed Old Red Sandstone and argillaceous schist, is the octophyllite mineral altogether absent. Here heptaphyllite illite makes up 80 to 90 per cent. of the crystalline clay and small quantities of kaolinite and hematite are also found. The influence of parent material is thus making itself felt although it would seem to be less effective in determining the soil clay mineralogy than the general climate of the area. In contrast to the basic igneous area of the Insch Association, hydrologic conditions in the slate and granite areas appear to have no effect at all on the types of clay minerals produced.

Differential Thermal Analysis. An investigation is in progress comparing the relative efficiencies and effects on clay minerals of three methods of removing free iron oxide from clays. The methods are: (1) the oxalic acid—ammonium oxalate method of Tamm; (2) the ammonium tartrate—aluminium method of Dion; (3) the sodium hydrosulphite method of Galabutskaya and Govorova. Results so far indicate that method (3) is the most rapid and convenient, and that it compares favourably with the others as regards efficiency in removing iron and effect on the clay mineral lattice.

A study of the mineralogical composition of Scottish soil clays by differential thermal analysis has been commenced. Briefly, this method consists of heating at a constantly increasing temperature a sample of the mineral or clay to be analysed and a sample of a thermally inert material, and, by means of a suitable thermocouple and recording arrangement, plotting the difference in temperature between the samples against the furnace temperature. A difference in temperature between the two samples occurs only when the minerals present decompose with absorption or evolution of heat, the curve obtained consisting of a straight line with a series of peaks corresponding to the mineral or minerals present. The peak temperature is then characteristic of the mineral and the area under the peak is a measure of the amount of mineral present. The sample is heated from room temperature to 1,000° C. in about 100 minutes, so the method is relatively rapid and lends itself to quantitative measurements probably more readily than any other.

The apparatus which has been constructed is based upon one in use at Leeds University, but the design has been modified somewhat to obtain practically automatic operation. In most of the equipment described in

the literature a nickel specimen holder containing samples of 0·4 g. is used, while samples of 0·8 g. in a ceramic specimen holder are used at Leeds. However, we have found that peaks of reasonable magnitude can be obtained with samples of only 0·2 g., using a ceramic specimen holder. This is a definite advantage when dealing with soil clays, where the amount of material available is frequently limited.

A series of forty pure minerals and mixtures of known proportions of pure minerals has been investigated to obtain standard data for the interpretation of results obtained with soil clays. The curves obtained for these minerals agree, generally, with published data although small amounts of impurities have been detected in several cases. About twenty soil clays have so far been investigated. The results agree well with X-ray data, but it would seem that some minerals observed on X-ray photographs do not give measurable peaks on thermal analysis curves. It is hoped to investigate qualitatively and quantitatively (1) variations in the clay mineralogy down the profile; (2) variations in composition between coarse (2·0–0·4 μ) and fine ($< 0{\cdot}4\ \mu$) material from the same soil clay; (3) variations between clays from different soil associations; (4) variations between clays from different drainage associates.

SOIL ORGANIC MATTER

In recent years the work of this section has tended to develop more definitely along the lines of fundamental research into the nature of soil organic matter—particularly of the humus complex, i.e. the alkali-soluble organic substances characteristic of soil.

The work is being developed along two main lines of approach (1) chemical and (2) microbiological. These two lines of investigation are being applied, (*a*) to the actual character of soil organic matter—especially of the humus complex, where the techniques are essentially chemical, with the microbiological aspect tending to supplement the chemical; (*b*) to the mode of decomposition of organic matter in the soil, in which the approach is essentially microbiological, and chemical investigation is used as an aid to the elucidation of the microbiology of soil processes. Until recently the process of composting has been used as a starting point because of the better microbiological focus which it provides for the study of organic decomposition.

Much of the time hitherto devoted to routine investigations and analyses of soils, peats and miscellaneous forms of organic matter has been diverted to the preparative and routine operations involved in the more fundamental research. Nevertheless a certain amount of such routine work has been undertaken along the lines indicated in previous reports.

Pot culture investigations have been carried out on the value of commercial materials submitted as soil conditioners and as sources of organic nitrogen. Experimental studies of the use of peat as a soil conditioner and source of organic matter have continued along the lines previously reported as a long-term investigation, but have not provided any new results of a definite noteworthy character

A considerable amount of advisory work in relation to peat and compost has been undertaken during the year.

The description and characterization of "humus types" in the field is being pursued in connection with the fundamental work on soil organic matter.

Chemical Investigations

Papers have been published on the isolation, purification and characterization of the major constituents of the humus complexes of soil organic matter of different origins,[6] and on the more soluble constituents of these.[7] The work reported in these papers has been extended over a wider range of soil types. One of the chief difficulties in technique in such investigations lies in the separation of flocculent humic precipitates and humic acid fractions from the water with which it forms a non-filterable mud. It is well-known that by freezing, colloidal gels may be made to coagulate, in some cases irreversibly. It has been found that when humic precipitates are frozen solid to a temperature of at least -3° C. and then allowed to thaw, the colloidal properties are altered, and the solid and liquid phases separate.[10] The solid is in a condensed form, forming irregular, microscopic flakes, which are very readily filtered by standard methods. The moisture content

has been reduced, for example, by a single freezing and thawing to one-thirtieth of that of the original muddy precipitate. The resulting condensed humic materials lose not only their water-holding capacity but also their adsorptive power. Thus, by washing with water, soluble contaminants are readily removed and a considerable degree of purification is quickly obtained. In the absence of electrolytes this condensation by freezing does not take place, since, on thawing, the material reverts to the soluble condition as water reforms.

This technique has greatly simplified the preparation of humic complexes in bulk. It is simply necessary to allow the acid-precipitated humus to settle, and, after siphoning off the supernatant liquor, to freeze to -3° C. On thawing the humic acid is readily filtered, washed and dried.

During the year attention has been concentrated on the soluble carbohydrates present in soil, and on the carbohydrate mucilages synthesized by soil bacteria, both in compost and *in vitro*.

Through the courtesy of Professor E. L. Hirst of Manchester University, facilities were given for studying and applying the most modern techniques of carbohydrate chemistry to soil polysaccharides, at that University for a period of six months during the past year, and soil carbohydrates are now being investigated using these methods.[11] The determination of the structural chemistry of soil "gum" is nearing completion. It is in the main a glucose-glucuronic acid, although other sugar units in lesser amounts contribute to the structure of the material.

In conjunction with this work on the carbohydrate complex of the soil, preparatory investigations have also been made of the more soluble nitrogen compounds present in soil, and this aspect of the general subject is now being tackled more specifically.

Microbiological Investigations

Work on the microbiology of the decomposition of organic matter in composts has been continued. Two types of material are being used for composting, viz. lawn mowings (rich in organic nitrogen) and straw (poor in organic nitrogen). Both materials are being composted under standard conditions in the open in specially adapted concrete drain pipes observing the usual criteria of making composts in practice, viz. adequate moisture and aeration, and prevention of the development of acid conditions during the period of decomposition.

In last year's report an account was given both from the chemical and microbiological aspects of the changes taking place in composts made from young fresh lawn mowings. It was found for this type of compost that the results obtained were in close agreement from both aspects.

A number of the thermophilic bacteria isolated from the grass compost have been sent on request to the American Collection of Type Cultures where a systematic study of this group is being undertaken.

This year most attention has been paid to the composting of straw; barley straw has been used, cut to about the length of the lawn mowings (1–3 inches). Its moisture content was adjusted as near as possible to that of the lawn mowings. The nitrogen content was made up to the figure suggested for the Adco process (about 2 per cent.)—ammonium nitrate being the source of nitrogen used. This was applied by spraying a solution evenly

over the cut straw and subsequently mixing well before placing loosely in the compost container.

Similar observations were made as for grass composts. The following may be recorded :

(1) *Moisture Content.* As in the grass compost this varied little over the composting period.

(2) *Behaviour of the Material.* Little sinking of the material took place as compared with the grass compost. Even after 100 days the straw compost had shrunk to only half of its original volume.

(3) *Temperature.* The temperature rose to about 62° C. This took place in 8–10 days. It will be remembered in the grass cuttings a similar rise was accomplished in 1–2 days. No dark coloured liquid oozed from the straw as it did from the grass compost during the high temperature phase. In fact no liquid of any kind drained from the straw compost at any stage during the study.

(4) *Microbiological Observations.* (*a*) *Aerobic mesophilic bacterial flora (developing on nutrient agar).* There is a reduction of the organisms present on the original straw by the time the high temperature is reached (62° C.). This does not appear to be as pronounced as in the grass compost. However, when the temperature falls there is a marked increase in this flora. This increase is followed by a slight but steady decline. It would therefore appear that in the composting of two quite different types of material the trend of the mesophilic aerobic bacterial flora is the same, viz. a reduction at the high temperature phase followed by a marked increase when the temperature falls into the range of the mesophilic organisms.

(*b*) *Thermophilic flora (developing on nutrient agar).* Thermophilic bacteria can be detected in the straw compost both by contact slide and plating techniques. So far it has not been possible to compare the extent of development of this type of flora with that on grass compost where it appears to play a considerable role. Unfortunately the colonies of many of the thermophilic bacteria spread so rapidly that they cannot be satisfactorily counted. However, preliminary observations do not show such an extensive development of thermophilic bacteria in the straw compost as compared with the composts made from lawn mowings.

(*c*) *Aerobic mesophilic cellulose-decomposing bacteria.* (Filter paper strip technique.) The behaviour of the aerobic mesophilic cellulose decomposing organisms for the straw compost over the composting period parallels that of the general mesophilic bacterial flora developing on nutrient agar described above.

There is a marked reduction at the peak of the rise in temperature, followed by an increase in numbers when the temperature falls. This is similar to the grass compost. In addition no aerobic thermophilic cellulose decomposers have been found by the technique so far employed. Chemical analyses also show that no cellulose disappeared during the high temperature phase in both types of compost.

(*d*) *Fungi.* In contrast to the grass composts general observations indicate that fungi appear to be much more abundant in straw composting, and a separate investigation has been started on this extremely important group of organisms.

SPECTROGRAPHIC ANALYSIS

The work of the spectrographic department can be sub-divided along the following lines :

(1) The spectrograph is being employed for the routine determination of numerous constituents, both major and trace, in soils, soil extracts, plant materials, biological materials, rocks and minerals. For the alkalis and alkaline earths in solution, the Lundegårdh flame emission method is applied, but for other determinations, particularly those of trace constituents such as cobalt, molybdenum, copper, etc., a cathode layer carbon arc technique has been developed, as decribed in earlier reports.

(2) The development of spectrographic technique, and the introduction of new methods of chemical pre-treatment of samples to suit such technique is being studied.

(3) In collaboration with other departments and external research institutions, the significance of the results obtained in relation to the healthy development of crops and animals is being investigated. Such work necessitates the determination of normal contents in soils, plants and biological materials before the interpretation of results obtained for abnormal samples can be satisfactorily carried out.

(4) Requests for tuition in the methods of spectrographic analysis by members of the staffs of outside institutions have been frequent and a considerable amount of time has been devoted to such work.

In the course of the year under review, grants from the Agricultural Research Council and the Department of Agriculture for Scotland have enabled additional equipment to be brought into use. This includes a Small and a second Medium Quartz Spectrograph, which should enable developments to be made in work on the more difficult elements such as zinc, as well as on the absorption spectra of soil organic matter. A recording microphotometer for this work is on order, in addition to a spectrophotometer, which it may also be possible to utilize as a direct reading instrument in conjunction with the Lundegårdh flame technique.

A short review of the application of spectrographic analysis to plants and soils has been published,[3] and a much longer technical communication on similar lines is in the press,[14] as is a further summarizing account of the work of the department and the results obtained.[20]

Spectrographic Analysis in the Cathode Layer Arc

This method is being employed for the determination of trace constituents extracted from soils by acetic acid and other extractants, and for the analysis of plant materials. A prior chemical concentration by means of mixed organic reagents (8–hydroxyquinoline, tannic acid and thionalide) is employed for this work if determinations of such elements as lead, tin, vanadium or chromium are required, otherwise precipitation with 8-hydroxyquinoline alone generally suffices, as cobalt, nickel and molybdenum are then recovered satisfactorily. An account of the concentration technique has been submitted for publication.[13] The possibility of employing liquid rather than

solid samples for application to the carbon electrodes is being studied, in conjunction with a method of concentration employing dithizone for the recovery of trace constituents, particularly from ferruginous and aluminous materials such as soils, rocks, minerals and possibly also metallic alloys, where the 8-hydroxyquinoline technique is not directly applicable. Preliminary results are promising for elements such as Co, Ni, Pb and Zn, but further work is necessary before the method can be applied on a routine scale.

An investigation is being made of the effect of electrode dimensions on the accuracy of the determinations in the cathode layer arc. As stated in last year's report some materials burn more satisfactorily with a larger admixture of carbon than normal, in a somewhat wider boring, and this work is being carried out in order to discover what range of variation is permissible without loss of accuracy, and to find out whether standard curves for different electrode dimensions are interchangeable.

The possibility of applying a graphical calculator to the evaluation of the trace element concentrations directly from the density readings of the trace element and internal standard lines has been investigated. It was found, however, that slight variations in the experimental conditions are more liable to cause errors in this method than in the blackening curve separation method which is normally employed. The precision obtainable by the use of a graphical calculator is necessarily less than that obtainable by the blackening curve separation method, and has been found to increase the standard deviation by some 2·8 per cent.

Some work has been carried out on an arc technique involving the use of compressed pellets on copper electrodes. The pellet is composed of the powdered sample in a spectrographic buffer. The method, although not so sensitive as the cathode layer technique, may have applications in the determination of certain elements, such as boron, in agricultural materials.

The scheme for the extension of spectrographic work to the Agricultural Colleges in the East and West of Scotland has involved the spectrographic department in a considerable amount of training and teaching work. Workers from other institutions in this country, as well as from overseas, have been at the Institute for periods of up to six months.

Members of the staff of the spectrographic department have represented the Institute at the Spectrographic Discussion Group meetings in Glasgow and at the meetings of the Absorptiometric Panel which deals with colorimetric methods. The former body has published a series of definitions of spectrographic terms.[1]

Trace Constituents in Soils and Plants

Application of the techniques mentioned above has led to considerable advance in our knowledge of the contents of various trace constituents in soils and in the vegetation which they support. A brief account of the present position has been presented to the XIth Congress of Pure and Applied Chemistry [21] and is awaiting publication. The investigation of animal disease problems, principally in collaboration with the Animal Diseases Research Association, has been continued, with the analyses of soils, plants and animal organs from affected and unaffected areas. This has included the study of cobalt deficiency in sheep, with analyses of food and excreta

designed to give an indication of the cobalt balance of cobalt-dozed and untreated animals. The cobalt contents of the soils sampled in the course of the survey of the cobalt deficient area in the south-west of Scotland have been determined.

Analyses of soils and plants from areas where yellowses of sheep is prevalent have been carried out, and the investigation is being continued, again in collaboration with the Animal Diseases Research Association, for a second season, in order to gain some confirmation of the trends established. The plants involved in those areas in the north-west include calluna and other constituents of rough grazing for which few data are available, and to obtain these, samples of similar vegetation from other areas are being examined. The uncertainty of the animal diet, and the difficulty of taking a composite sample has led us to examine individual constituents of the herbage, rather than a bulk sample.

Geochemical investigations of soils, rocks and minerals have been continued. The trace constituents in granites from different parts of Britain are being studied in collaboration with workers at the University of Edinburgh and the Royal School of Mines, whilst collaboration with Professor Wager of Durham and Dr. S. R. Nockolds of Cambridge has also been continued. The communication on the distribution of trace elements in Scottish igneous rocks and their constituent minerals, referred to in the last report, is now on the point of publication.[12]

Spectrographic Analysis in the Lundegårdh Flame

The chemical determination of alkalis and alkaline earths, particularly the former, is a matter of considerable difficulty on a routine scale, and the bulk of the determinations of potassium and sodium required in the Institute are being carried out spectrographically by the Lundegårdh technique. The principal application has again been to the determination of the amount of potassium extracted from soils by dilute (2·5 per cent.) acetic acid for soil advisory purposes. Other analyses have included determinations in plant materials, rocks and minerals after the intial stages of the Lawrence Smith extraction, solar salts and similar materials. The number of plates each carrying sixteen samples examined by two technical assistants for up to four constituents per sample is approximately 450 per annum.

PLANT PHYSIOLOGY

The work of the Plant Physiology Department has been planned to include the laboratory and field study of the soil-plant relationship. It has consisted mainly of investigations in the sphere of plant nutrition, especially the absorption, translocation and utilization of nutrients by plants, and methods of diagnosing abnormal soil nutritional conditions by means of the plant. At present, most of the investigations have not proceeded beyond the introductory stages.

Plant Nutrition

Factors in the nutrition of oat, swede, potato, tomato and strawberry crops have been investigated by the analysis of samples previously accumulated and by sand-culture and field experiments, and preparations have been made to extend these studies to other agricultural and fruit crops, the raspberry being particularly important among the latter. Special prominence has been, and will be given to the fundamental aspects of magnesium deficiency, to the effect of ion antagonism on absorption, to the effect of nutrient supply on the translocation of nutrients within the plant, and to the relationships between soil treatment, yield, plant composition and disease resistance.

In addition to the above crops, the nutrition of bracken is being investigated and both normal and abnormal types are being examined.

Diagnosis of Nutritional Abnormalities

The accurate determination of the cause of abnormal plant growth and development is of considerable importance in many branches of research as well as in agricultural advisory work, and this is none the less so when the cause is nutritional in character. The identification of these nutritional abnormalities is receiving considerable attention, the mode of approach being by way of the plant itself. Prior place has been given to the study of fundamental features in the plant-analysis technique and to the comparison of results obtained by this technique with those obtained by visual examination of the plants ; in some cases these methods have also been compared with the injection, spraying and soil-analysis techniques. Field experiments on the oat, swede and potato crops, involving various levels of nitrogen, phosphorus and potassium, and single and multiple deficiencies of these, and sand-culture experiments on the tomato crop, involving magnesium, iron, manganese, etc. have been used to determine which part of the plant, and which fraction of the nutrients therein, is the best index of the nutrient status of the plants. Immature, mature and senescent types of both actively metabolizing tissues (leaf laminae) and conducting tissues (stems and petioles) have been sampled ; they are being used to compare the total amounts of the nutrients present with the fractions extracted from the dry-matter and fresh material by water, ether-water and sodium acetate - acetic acid buffer solution of *p*H 4·8, the materials being either shaken with the extrac-

tants or macerated with them in a Waring Blendor. It is presumed that the range of both crops and nutrients will be considerably extended in the future.

Work on the injection of the tomato plant has confirmed that injection through either a truss stalk or a leaf petiole affects only part of the plant. The value of the injection diagnostic technique for the tomato plant is thus shown to be greater than was formerly believed ; previously it was thought that injection affected the whole plant.

A system for the routine determination of the nutrient status of plants has been established. In addition to being useful in advisory work this should also lead to the better understanding of nutritional problems and should be a useful source of material for the further investigation of such problems. So far, the nutrients usually dealt with on this routine basis have been nitrogen, phosphorus, potassium, calcium, magnesium and manganese, but in future this range will be extended.

Analytical Methods

Much of the above work necessitates the analysis of numerous samples and for this purpose chemical methods have been utilized. In order to strike a balance between speed and accuracy in these analyses, methods involving the use of the Spekker Photoelectric Absorptiometer have been adopted ; the rapid methods sometimes used in this type of work had been previously tried and found to be too unreliable. The choice of suitable chemical methods has involved a considerable amount of investigation ; this was particularly so for magnesium, but a method was eventually evolved which is suitable for the examination not only of soils and plants but also of such materials as milk and blood.

SPECIAL INVESTIGATIONS

Collaboration with the Animal Diseases Research Association

The study of the relation of mineral, including trace element contents of soils and plants to the incidence of disorders in animals has been continued in collaboration with the Animal Diseases Research Association. As indicated in the section dealing with soil geology, further studies have been made on the soils of Kirkcudbrightshire where pining in sheep has been shown to be due to shortage of cobalt. Trace element determinations have been made spectrographically on samples from areas on which cobalt deficiency, lactation tetany, yellowses and other animal disorders occur.

Collaboration with the Rowett Research Institute

Various pasture species have been grown in pots for use in Fistula experiments which are being carried out by the Rowett Institute. Several samples of ingredients of synthetic diets have been analysed spectrographically.

Collaboration with the Forestry Commission

Studies on the nutrition of forest tree seedlings are being continued and the Institute is represented on a sub-committee appointed by the Forestry Commission to deal specifically with this subject.

Agricultural Research Council

The Institute is represented on the Council's Conference on Methods of Fertilizer Application to Agricultural and Horticultural Crops. The study of different methods of appyling fertilizers has been undertaken with the aid of a grant from the Council.

Consultative Committee on the Development of Spectrographic Work

The Consultative Committee—constituted by the Agricultural Research Council and the Department of Agriculture for Scotland with the Director of The Macaulay Institute as Convener—represents all the Research Institutes in Scotland interested in spectrography, the Scottish Colleges of Agriculture and the Research Division of the Ministry of Agriculture of Northern Ireland.

A technical sub-committee representative of the active workers in this field of investigation was formed to deal with detail. The parent committee will review the various aspects of pure and applied spectrography.

Spectrographic laboratories are being established at the East and West of Scotland Colleges of Agriculture and facilities for the training of personnel have been offered by The Macaulay Institute.

PUBLICATIONS

(A) *Issued during the year—*

1. " Suggested Definitions of Terms Used in Spectrographic Analysis." (Spectrographic Discussion Group Publication No. 1, 1946.)
2. " Activity of Thermophilic Bacteria in Composts of Fresh Green Material." By D. M. Webley. (*Nature* **159,** 35, 1947.)
3. " Spectrographic Analysis of Plants and Soils." By R. L. Mitchell. (*Biological Reviews,* **22,** 1–29, 1947.)
4. " Distribution of the Total and Acetic-soluble Phosphate in Soil Profiles having Naturally Free and Impeded Drainage." By R. Glentworth. (*Nature,* **159,** 441, 1947.)
5. " Forestry in the Scottish Highlands." By G. K. Fraser. (*Scottish Mountaineering Club Journal,* **23,** 384–397, 1947.)
6. " The Characterization of the Humic Complexes of Soil Organic Matter." By W. G. C. Forsyth. (*J. Agric. Sci.,* **37,** 132–138, 1947.)
7. " Studies on the More Soluble Complexes of Soil Organic Matter. I. A Method of Fractionation." By W. G. C. Forsyth. (*Biochem. J.,* **41,** 176–181, 1947.)
8. " Memoranda on Colonial Fertilizer Experiments. I. Planning and Conduct of Fertilizer Experiments." By A. B. Stewart. (*Colonial No.* 214. H.M. Stationery Office, 1947.)
9. " Report on Soil Fertility Investigations in India with Special Reference to Manuring. (A Review of the Position to Date with Suggestions for the Planning and Conduct of Future Experiments.") By A. B. Stewart. (Printed at the Army Press, Delhi by the Indian Council of Agricultural Research, 1947.)

(B) *In preparation—*

10. " Freezing as an Aid in the Drying and Purification of Humus and Allied Materials." By W. G. C. Forsyth and G. K. Fraser. (To appear in *Nature.*)
11. " Colour Reagents for the Paper Chromatography of Sugars." By W. G. C. Forsyth. (To appear in *Nature.*)
12. " The Geochemistry of some Caledonian Plutonic Rocks: a Study in the Relationship Between the Major and Trace Elements of Igneous Rocks and their Minerals." By S. R. Nockolds (Cambridge University) and R. L. Mitchell. (To appear in *Trans. Roy. Soc. Edin.*)
13. " Concentration Methods in Spectrographic Analysis. II. Recovery of Trace Constituents in Plant Materials and Soil Extracts by Mixed Organic Reagents." By R. L. Mitchell and R. O. Scott. (To appear in *J. Soc. Chem. Ind.*)
14. " The Spectrographic Analysis of Soils, Plants, and Related Materials." By R. L. Mitchell. (To appear as *Tech. Comm. No.* 44 *of Commonw. Bur. Soil Sci.,* Price 12*s.* 6*d.*)
15. " Complexes of Clays with Organic Compounds. I. Formation between the Clay Minerals Montmorillonite and Halloysite and Organic Liquids." By D. M. C. MacEwan. (To appear in *Trans. Faraday Soc.*)
16. " Complexes of Clays with Organic Compounds. II. Investigation of the Ethylene-glycol-water-montmorillonite System Using the Karl Fischer Reagent." By R. C. Mackenzie. (To appear in *Trans. Faraday Soc.*)
17. " The Relative Effectiveness of Phosphatic Fertilizers." By E. G. Williams and J. W. S. Reith. (To appear in *Emp. J. Expt. Agric.*)
18. " Placement of Mineral Nutrients in Soils." By A. B. Stewart. (To appear in *Trans. XIth International Congress of Pure and Applied Chemistry.*)
19. " The Association or Hydrologic Sequence in Certain Soils of the Podzolic Zone of North-east Scotland." By R. Glentworth and H. G. Dion (University of Saskatchewan). (To appear in *Brit. J. Soil Sci.*)
20. " Trace Constituents in Soils and Plants: Their Significance and Spectrographic Determination." By R. L. Mitchell. (To appear in *Research.*)

21. "The Trace Constituents of the Soil." By R. L. Mitchell. (To appear in *Trans. XIth International Congress of Pure and Applied Chemistry.*)
22. "A Modified Hydrometer Method for Mechanical Analysis of Soils." By A. Muir (Rothamsted Experimental Station) and G. Robertson.
23. "Colorimetric Determination of Aluminium in the Presence of Small Amounts of Iron." By G. Robertson.
24. "The Absorptiometric Determination of Magnesium." By J. G. Hunter.
25. "The Mineralogical Composition of Soils from Northern Aberdeenshire." By R. Hart.

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