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Soil research in Scotland[2]

Soil research in Scotland is centred at the Macaulay Institute for Soil Research in Aberdeen. The Institute is one of eight agricultural research institutes in Scotland financed by the Department of Agriculture and Fisheries for Scotland, with the scientific advice of the Agricultural Research Council, an organization covering the whole of Great Britain, that is England, Scotland and Wales, but not Northern Ireland. The eight institutes are:

Rowett Research Institute for Animal Nutrition, Aberdeen
Scottish Plant Breeding Station, Edinburgh
Animal Diseases Research Association, Edinburgh
Macaulay Institute for Soil Research, Aberdeen
Hannah Dairy Research Institute, Ayr
Scottish Horticultural Research Institute, Dundee
Hill Farming Research Organisation, Edinburgh
National Institute of Agricultural Engineering, Scottish Station, Edinburgh.

In Scotland there are also a number of Agricultural Research Council establishments including the Animal Breeding Research Organisation, a Poultry Research Centre and a Statistics Unit.

The institutes are not teaching establishments, but can provide facilities for a limited number of visiting research workers. For undergraduate instruction there is a department of Soil Science at the University of Aberdeen, and agricultural courses of degree standard at the Universities of Aberdeen, Edinburgh and Glasgow. In addition there are three Colle-

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[2] Sitzung der Naturforschenden Gesellschaft in Bern vom 22. Mai 1964.

ges of Agriculture centred on these cities, under the Department of Agriculture and Fisheries for Scotland, which organize more practical diploma courses in all branches of agriculture. The Colleges are responsible for providing advisory services for farmers over the whole of Scotland and work in collaboration with the research institutes. Advisory officers based in the Colleges bring into practical application the findings of field and laboratory research work carried out both in the Colleges and the Institutes. College advisory services cover animal husbandry and crop production, and about fifty percent of farmers take advantage of advisory services covering soils and fertilizers, which are provided free of charge to all who desire them.

Of the 7,7 million hectares of land surface in Scotland, only 1,7 million, or slightly over one-fifth, is cultivated, the remainder being largely moorland and rough grazing. The distribution of population varies from several hundred per square kilometre in the industrial areas of the central lowlands to less than 3 in the more mountainous areas in the north and west. The mountains rise to over 1300 metres in this region, while the south of the country consists of rolling hills rising to 600 metres or so. The rainfall varies from 50—75 cm per annum in the east to over 250 cm in the northwest, fairly evenly distributed throughout the year.

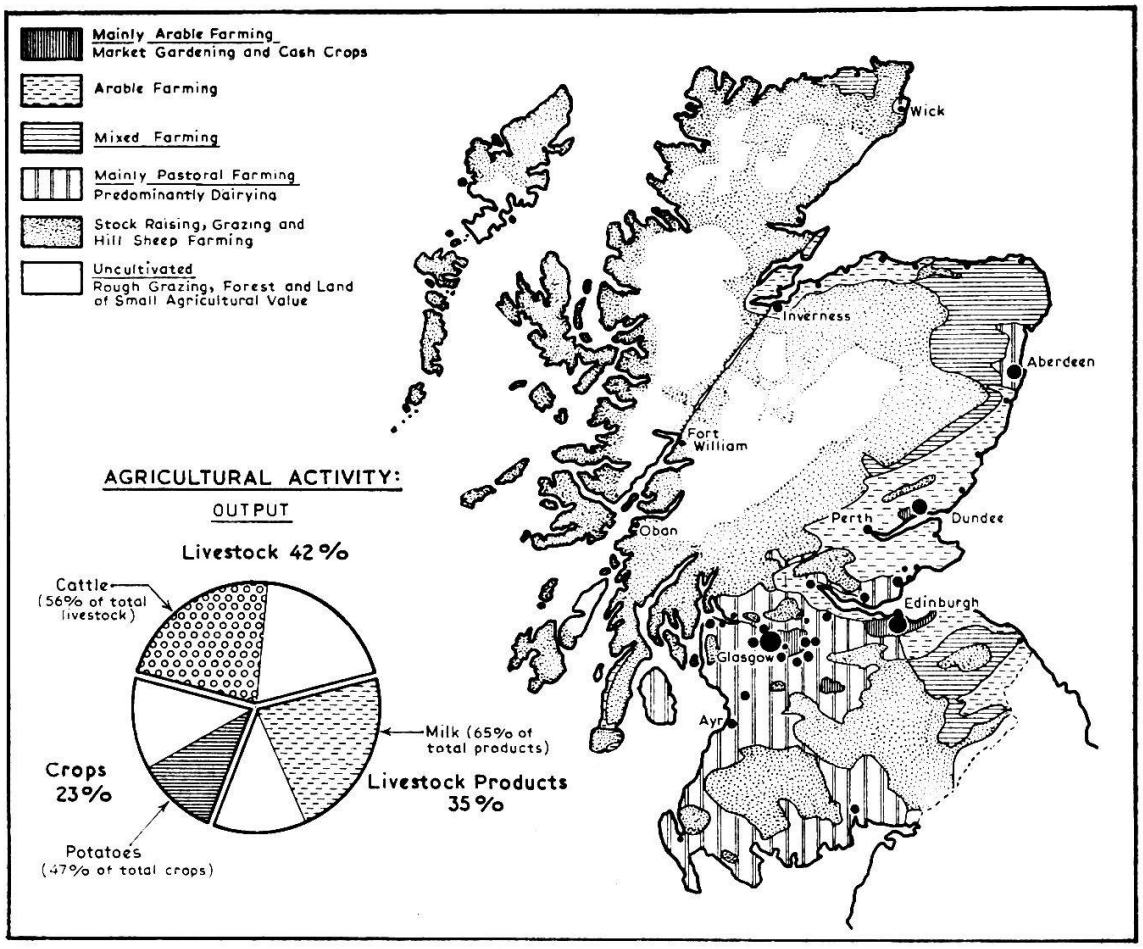
In 1962, the areas under the principal crops were as follows, in thousands of hectares: grass (grazing) 861; grass (hay or silage) 269; oats 231; barley 144; turnips and swedes 89; potatoes 57; wheat 44; sugar beet 6; vegetables for human consumption 5.

Stocks of animals in the same year were: cattle (beef) 1 259 000; cattle (dairy) 758 000; sheep 8 639 000; pigs 466 000; poultry 8 821 000. Most of these animals are raised in or near the arable regions of the east coast, the central lowlands and the south-west. The normal rotation is commonly based on one to four years grass and clover followed by a cereal, a root-crop and a cereal undersown with grass and clover. Many of the sheep are raised on the rolling pastures of the Southern Uplands and the rough grazings of the Highlands. It would not be difficult to improve the stock-carrying capacity of the hill-land for a few months in summer; the practical difficulty arises in making provision in winter for an increased number of animals, except in more favourably situated areas. Much of the hill-land which has carried only erica and calluna in recent times is being afforested with imported conifers.

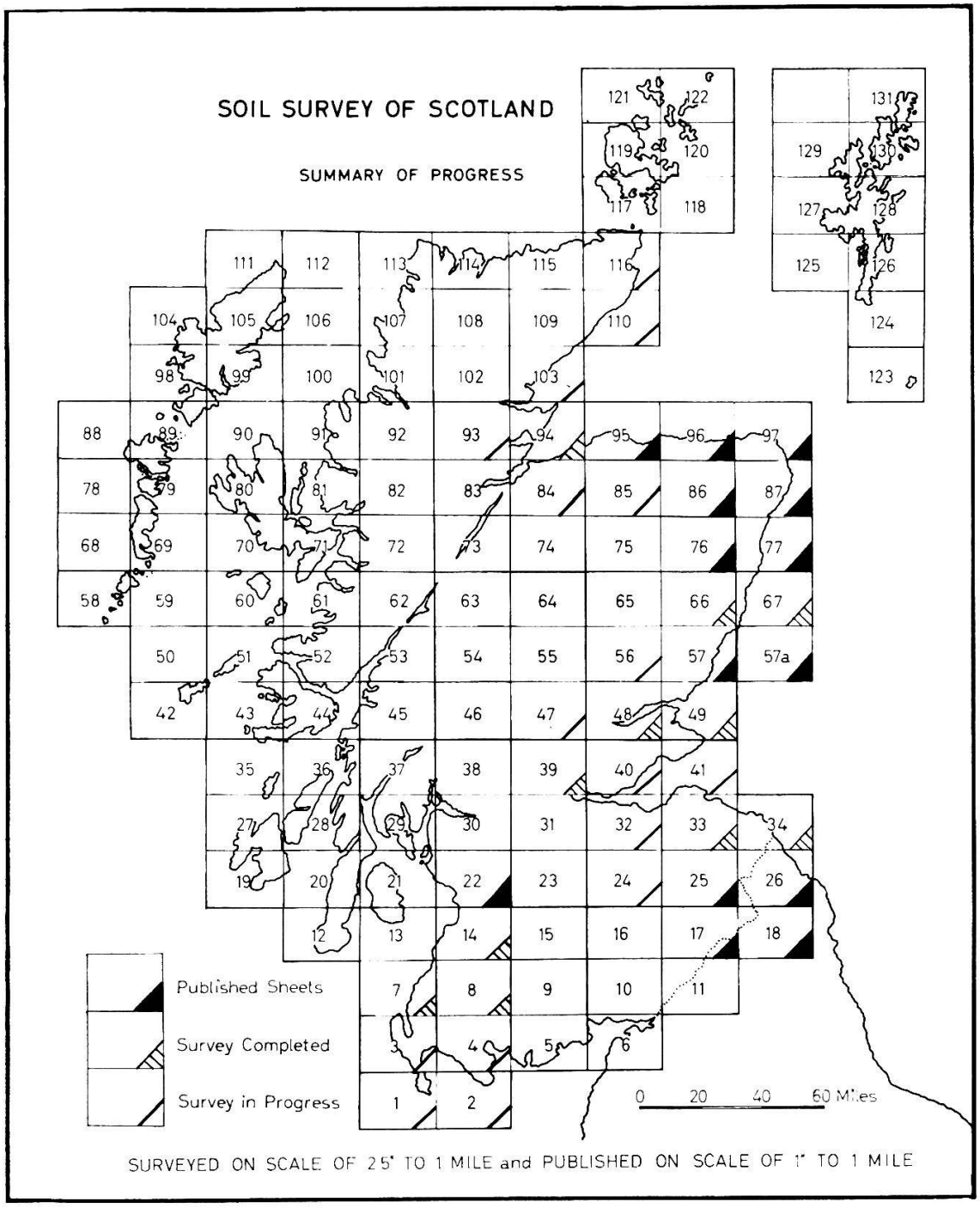
The geology of Scotland is rather complex. In the north and west are the older metamorphic rocks such as Lewisian gneiss and the Dalradian

and Moine schists, with intrusions of all forms of igneous rocks and extensive areas of Old Red Sandstone and Torridonian Sandstone rocks. The central lowlands are largely very variable Carboniferous sediments with basic igneous intrusions, while the southern uplands are composed mainly of Silurian slates and Old Red Sandstone and Carboniferous sediments with igneous intrusions. The whole country has been subjected to several periods of glaciation. Three have been recognized in the north-east. As a result, there is everywhere a covering of till of variable depth over the underlying rock, and this till may have been derived locally or have been transported many kilometres. This is the material on which Scottish soils have developed during the past 10 000 years.

The Macaulay Institute for Soil Research was founded in 1930 in a mansion house on the outskirts of Aberdeen, following a benefaction from Dr. T. B. Macaulay of Montreal, Canada, who desired to do someth-



The Agricultural Utilization of the Soils of Scotland.
Diagram drawn by Goodwin and reproduced by permission of
« The Scotsman », Edinburgh.


SOIL SURVEY OF SCOTLAND
SUMMARY OF PROGRESS
Published Sheets
Survey Completed
Survey in Progress
0 20 40 60 Miles
SURVEYED ON SCALE OF 25" TO 1 MILE and PUBLISHED ON SCALE OF 1" TO 1 MILE

ing to improve the agricultural conditions in the rather poor areas of the Scottish Highlands and Islands from which his ancestors came. The staff in 1931 was 8, in 1945, 38, and it has now risen to 199. The first director was Dr. W. G., now Sir William, Ogg: he was succeeded in 1945 by Dr. D. N. McArthur and in 1958 by the present director, Dr. A. B. Stewart. New Institute premises were completed in 1962 in the original 25-hectare grounds.

The work of the Institute is distributed through seven major departments, namely Soil Survey, Pedology, Biochemistry, Microbiology, Plant Physiology, Soil Fertility and Spectrochemistry. In addition, there is a small Statistics section, a specialized Library and an Instrument Workshop where many pieces of apparatus are constructed or modified to meet the specialized requirements of the Institute.

The Institute publishes an Annual Report detailing the investigations in progress and has already produced seven volumes of Collected Papers which include most of the 530 scientific papers which have appeared in journals and conference proceedings.

Soil Survey of Scotland

The function of the Soil Survey of Scotland, with a staff of 16 surveyors under Dr. R. Glentworth, based at the Macaulay Institute, is to make an inventory of the soil resources of the country. It produces maps on a scale of 1 : 63 360 (1 inch to 1 mile) and descriptive memoirs for areas of approximately 1000—4000 sq. km covered by one to four sheets of the soil map. The soils of some ten percent of the land area of Scotland have been surveyed, and an equal area is at present being mapped, as the diagram indicates. It will be observed that the survey has so far concentrated on the agriculturally important areas, and a large proportion of the arable land has therefore already been dealt with.

After a preliminary reconnaissance of an area, the surveyors carry out systematic mapping by excavating soil profiles to a depth of over one metre at separations depending on the variability of the soil. Soils are described by the nature of the various layers or horizons exposed in a pit and samples of each horizon are taken for laboratory examination. Closely similar soils are grouped together in a Soil Series which is given a name of local origin, unless the series has previously been described elsewhere, when the earlier name is used. Different series related pedo-

logically are grouped into a Soil Association which is named after the most important series in the association. In Scotland, an association generally includes soils derived from one soil parent material: its constituent series are commonly defined by topography and drainage conditions. The predominant effect of parent material probably arises because the soils are never more than 10 000 years old.

The usual distribution of the different soil series within an association passes from hill peat on the hill tops through various types of podzols and freely drained brown forest soils on the slopes to gleyed soils in the poorly drained valley floors and basin peats in the hollows. In the soil maps, freely drained soils are represented by a red or brown coloration and poorly drained by blue or green, so that an impression of the drainage status of the various series present is immediately obtained.

In Scotland, which is within the podzolic zone, peats, peaty podzols and iron podzols are the predominant major soil groups in the north and west, grey-brown podzolic soils, brown forest soils and gleys in the central lowlands and a mixture of brown forest soils, grey-brown podzolic soils and podzols in the Southern Uplands. The typical Scottish iron podzol has marked profile differentiation with a well developed thin iron-rich hard pan. Such pedological features near the surface tend to be obscured by the processes of cultivation. The ground water gleys, on the other hand, are characterized by the blue-green coloration or mottling even in arable soils, and are readily recognized.

The findings of the Soil Survey are applied by other departments of the Institute in general soil investigations and fertility studies. It should be emphasized that it is not the function of Soil Survey to assess the agricultural potentialities of soils or to pronounce on land-use. These involve consideration of more factors than soil classification requires.

Pedology

In the department of Pedology, Dr. R. C. Mackenzie has a staff of over 30 workers who are concerned, in the Chemistry and Mineralogy section, with the study of the fundamental processes which bring about the change from inert rock to living soil, and, in Peat and Forest Soils, with the pedological aspects of these materials. Samples from typical soil profiles are examined in this department for such characteristics as exchangeable cation content, mechanical composition, and the properties

of the clay fraction. More fundamental investigations are concerned with such topics as the nature of the soil clay minerals which develop under varying pedological conditions with different soil parent materials. Thus, it has been found that illite predominates in soils of granitic, metamorphic and sedimentary origin, while montmorillonite and vermiculite occur in soils derived from basic rocks, montmorillonite being more abundant in poorly drained soils. Considerable attention is being paid to the constitution and properties of the clay minerals themselves. Such studies have involved the application of x-ray diffraction techniques. The use of glycerol and ethylene glycol for the identification by x-ray techniques of minerals exhibiting intra-crystalline swelling was pioneered at the Institute. More recently, electron microscopy has been introduced. Dr. Mackenzie has himself been particularly interested in the development of methods of differential thermal analysis, and apparatus developed in the Institute is now available commercially. In this technique, endothermic or exothermic energy changes within a mineral, resulting from recrystallization or change in composition, for instance by loss of water or ammonia, as the temperature changes, can be studied. The related technique of thermogravimetric analysis is not affected by recrystallization effects, in which the total weight of the material does not alter, and so provides useful supplementary information. Differential thermal analysis is of value not only for the detection and estimation of very small amounts of certain minerals in soil clays: using controlled atmosphere techniques it is providing useful information on the organic fraction of the soil. It has also been used with considerable success for the examination of the amorphous inorganic constituents of soils, which appear to be much more abundant in Scottish soil clays than had been appreciated.

In this work on soil clays, use is also made of the methods of infrared absorption, carried out collaboratively with Dr. V. C. Farmer in the department of Spectrochemistry. The infrared technique provides a means of examining the nature of the chemical bonds and inter-atom vibrations within a molecule, and it is very useful in locating and characterizing OH groups and bound water within the soil clay minerals. In such studies, the effects of heating and evacuation and of the introduction of different exchangeable cations into soil clay minerals can be investigated.

Other aspects of work in Pedology include the study of forest soils and peats, rather specialized aspects of soil genesis. Scotland has large areas of deep peat in both the highlands and lowlands. Practical reclamation

studies and more theoretical investigations, including pollen analysis, are in progress. A survey of the peat deposits in Scotland is being carried out. Work on forest soils is carried out in collaboration with the Forestry Commission and includes forest nursery experiments.

Biochemistry

In the department of Biochemistry, under Dr. J. S. D. Bacon, the aim is to investigate the role of soil organic matter. To this end, more must be learnt about the chemistry of the complex constituents of plants which are the parent materials of soil organic matter, and about the chemical changes brought about by the micro-organisms which transform and destroy it. It is also desirable to know how soil organic matter may influence the growth and composition of plants. Thus, there is close cooperation between Biochemistry and both Microbiology and Plant Physiology.

The topics at present being studied most closely are the chemistry of humic acids and of the water-soluble polysaccharide fractions of soils. The polysaccharide fraction of Scottish soils has, for instance, been found to contain small amounts of methylated sugars and work is in progress in order to ascertain whether these come directly from plant residues or whether they are secondary products of bacterial origin.

The laboratories are equipped for the separation and purification of compounds of high molecular weight, but considerable emphasis is also placed on the complete chemical characterization of smaller molecules derived from them. Various types of chromatography, including partition and absorption chromatography on columns, analytical and preparative paper chromatography, and vapour phase chromatography are employed. Experimental plant material is grown in controlled conditions of temperature, humidity and illumination. When necessary, it is dealt with within minutes of collection in a small laboratory maintained at 4 ° C in order to minimize metabolic changes between collection and extraction.

Microbiology

The department of Microbiology, under Dr. D. M. Webley, is concerned with the role of soil microorganisms in the decomposition of organic

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matter, with the functions of microorganisms in relationship to the nutrition of higher plants, for instance their possible role in making available nutrients present in difficultly soluble minerals, and with fundamental studies of the more important organisms involved in such processes.

In the new building, appropriate precautions to ensure freedom from biological contamination have been taken. The plastic-topped benches have proved very successful, and where necessary air sterilization by ceiling-suspended ultraviolet units has been installed.

The breakdown of substances related to lignin by soil fungi has been studied, with extensive use of the facilities for ultraviolet and infrared absorption provided by the department of Spectrochemistry to enable the intermediate products to be identified. Considerable attention has been given to the study of micro-organisms which attack phosphate minerals. It has been found that certain soil bacteria such as nocardia which produce 2-ketogluconic acid are very effective in dissolving rock phosphate. An extension of this work has shown that such organisms can also decompose silicate minerals. Many soil fungi, particularly those which produce citric and oxalic acid, have also been investigated in this connection. Other work has included studies on the breakdown of organophosphate compounds and on the occurrence of organisms which produce polysaccharides in the rhizosphere or root-region of pasture grasses. Work on soil protozoa has just been started.

Plant Physiology

The main emphasis of the work in Dr. P. C. DeKock's department is directed towards the mineral nutrition of plants. While the soil aspects are not ignored, most of the investigations are concerned with the growth of plants in solution cultures in precisely controlled conditions. A cold-room allows manipulation of plant material at near freezing temperatures. Growth cabinets provide control of illumination, temperature and relative humidity, and plant material obtained under strictly controlled and reproducible conditions can therefore be obtained for experimental work. Dr. DeKock has been particularly interested in the iron status of chlorotic and healthy plants, and this work has led to the postulation of correlations between the phosphorus-iron, manganese-iron and potassium-calcium ratios in the plant. In collaboration with the department of Biochemistry, a significant correlation between malic acid and calcium

in plants has been demonstrated, similar to that previously reported for citric acid and calcium. These correlations also appear to affect the trace element status of the plants, possibly through their influence on the redox potential of iron. The relevance under field conditions of such relationships demonstrated largely in laboratory culture has still to be confirmed, and their importance evaluated, but they should in due course help in the understanding of mineral deficiencies.

Another aspect of work in Plant Physiology is the study of the mechanism of transport across the plant cell membrane. This is being examined in storage tissues such as slices of potato tubers or beet roots. This type of work is now being done under aseptic conditions in collaboration with Biochemistry.

Experiments on the uptake of organically complexed trace elements by plants, in collaboration with the department of Spectrochemistry, have indicated that chelated trace elements can be specifically taken up or rejected by plants depending on the nature of the chelate and of the chelated element.

A section of the work in Plant Physiology is concerned with the use of radioactive isotopes in soil and plant: soil investigations. This technique has been applied to the study of ion movement across cell membranes, and in collaboration with Soil Fertility, to the assessment of the phosphate status of soils.

Soil Fertility

The research programme in the department of Soil Fertility under Dr. E. G. Williams is designed to elucidate the significance of the various pedological factors in relation to crop production. Field, pot and laboratory studies cover individual plant nutrients with the different agricultural crops on the important soil series mapped by the Soil Survey. The field programme comprises some 60 experiments annually on private farms, set up to study the immediate and residual effects of lime, phosphorus, potassium, nitrogen, trace elements and farmyard manure on the yield and composition of produce. Field sites representative of recognized soil types are chosen in consultation with the department of Soil Survey. Under Scottish conditions, there is a general deficiency of phosphate and particularly lime, although many of the soils have now been brought to the desirable level of pH 6,0—6,5. The situation regard-

ing potassium is generally more satisfactory. The department collaborates closely with the North of Scotland College of Agriculture in soil advisory work and so maintains a direct practical interest in the agricultural applications of its findings.

Field experiments are designed to conform with modern statistical requirements and are repeated over a number of years to cover seasonal climatic variations. The results of such experiments are of direct practical importance, as, in combination with pot experiment and laboratory results, they enable advisory recommendations on cropping programmes to be formulated and the most advantageous fertilizer compositions to be used on the various soil types. In addition, the field programme covers such factors as the form, frequency, time and method of application of fertilizers. Much attention has recently been devoted to the placement of fertilizers and cultivation procedures, particularly for phosphate, because of its low mobility in soils. Combine drilling of phosphate with cereal seed may be twice as effective as broadcast application.

The fundamental relationship between crop performance and basic soil properties is often obscured in the field by local factors such as soil depth, drainage conditions, micro relief and biological factors: these can be virtually eliminated under pot conditions. Once the field: pot relationship has been established, pot experiments can partially replace field experiments for some purposes, such as the study of the residual effects of phosphate. The pot experiment serves as a useful link between field and laboratory, but it cannot ever replace the former entirely.

Because of its practical importance in Scotland, much attention has been given to laboratory studies of soil phosphate. The marked effects of both soil parent material and soil drainage on its content and availability in the predominantly acid soils of Scotland can be largely explained in terms of the amounts of soluble aluminium and iron. These determine the phosphate retention capacity and also the degree of saturation with phosphate, which governs the solubility and the intensity of the supply to plants. The retention capacity of a soil for phosphate is considered to be a soil characteristic of fundamental and general importance. While Scottish soils vary greatly in their extractable phosphate contents, all have approximately the same percentage phosphate saturation. The effect of drainage status on phosphate requirement is quite important. Because of the low content of extractable aluminium in poorly drained soils, the desired percentage saturation can be achieved with much smaller dressings of phosphate fertilizer.

Spectrochemistry

In the department of Spectrochemistry the chief interest has been in the distribution and availability of trace elements in Scottish soils. The department has a staff of 23, and there are generally 2 or 3 visiting research workers.

Spectrochemical methods are used for the flame photometric determination of such biologically essential elements as K and Ca, up to 20 000 determinations per year being made for other departments on three-channel flame photometers built in the department. A solution-spark excitation method with direct-reading measurement is used for Mg in up to 10 000 samples per year, also mainly for diagnostic analyses carried out in the department of Soil Fertility.

The chief applications of spectrochemistry are, however, for trace element problems. Methods for the determination of trace elements in soils and plant materials have been developed within the department, notably by R. O. Scott, and widely adopted in other laboratories throughout the world. These methods allow determinations of many trace elements down to one part in one hundred million to be made in plant materials and soil extracts. They are described in Technical Communication No. 44A of the Commonwealth Bureau of Soils, entitled «The Spectrochemical Analysis of Soils, Plants and Related Materials». For this work the department employs 3 Hilger Large Quartz Spectrographs, a Hilger Medium Direct Reader and an atomic absorption unit built in the department. Most of the work involves excitation by cathode layer direct current arc in carbon electrodes, but porous cup solution spark methods are also used.

Quite a large area of Scotland is deficient in one or other of the essential trace elements, but because of the geological complexity, the deficiencies arise in relatively small isolated areas scattered throughout the country. It is therefore not possible to take remedial measures on a regional basis: each farm or even each field must be considered separately.

Most widespread is a deficiency of available soil cobalt, in soils of arenaceous or granitic origin, leading to a pasture herbage content of less than 0,08 ppm cobalt in the dry matter. Sheep grazing such herbage develop the disorder known as pining, which is a vitamin B_{12} deficiency caused by insufficient cobalt available to the rumen bacteria which produce this vitamin. By adding two kilograms of cobalt sulphate per hec-

tare to a cobalt deficient soil the live weight of a six-months old lamb can be raised from 20 to 40 kg.

There is no evidence of molybdenum deficiency in agricultural crops in Scotland, in fact large areas are on the verge of excess molybdenum as far as cattle tolerance to molybdenum in pasture herbage is concerned, contents in the dry matter being several parts per million. There would be a danger of molybdenum toxicity if even a few grams per hectare were added in fertilizers, particularly if lime were also applied to bring the pH of the predominantly acid soils to near neutrality.

The importance of copper deficiency problems appears to be increasing. They are most marked with cereal crops on light sandy soils, where in deficient areas the yield of oat or barley grain may be doubled by the addition of 20 kg of copper sulphate per hectare to the soil. The disease of lambs known as swayback can be prevented by administration of copper to the pregnant ewe, but is seldom directly correlated with soil or herbage copper content.

Some deficiency of manganese in cereals has also been found, generally on the same soils as copper deficiency occurs, or on calcareous raised beach soils in the Western Isles.

There are considerable areas of boron deficiency in root crops, which apparently becomes more serious as the liming programme is intensified. It is now standard practice to employ boronated fertilizers in such areas.

No evidence of selenium excess leading to stock disorders has been found, but recent work suggests that selenium is concerned in some vitamin E deficiencies such as muscular distrophy in cattle, and that dosing with a few milligrams of selenium per month may on some arenaceous soils increase the live weight of lambs slightly. The amounts of selenium involved are so small that soil treatment is considered dangerous.

It is thus obvious that there are considerable trace element problems to be investigated in Scotland. In addition to the diagnostic analysis of soils, plants, and, in collaboration with other institutes, animal organs, the department of Spectrochemistry is engaged in the study of the source, modes of occurrence and availability of trace elements in soils and of their uptake by and distribution in plants. It has been observed, for instance, that there is a close correlation between total trace element content and the geological nature of the soil parent material, and that the availability of many trace elements is greater in poorly drained than in freely drained series of the same soil association.

Thus, as a result of inter-department collaboration, soil research in Scotland is organized from the Macaulay Institute as an integrated operation in which the soil surveyors are cataloguing the soils, the scientists in Pedology, Biochemistry and Microbiology are studying the fundamental processes involved in soil formation, while in Plant Physiology, Spectrochemistry and Soil Fertility the practical implications of the findings are investigated and the benefits passed to the farmer through the advisory services of the Colleges of Agriculture.

By far the most important remedial treatment in Scottish soils is the use of lime. Apart from this, significant practical aspects of soil research are concerned with the behaviour of phosphate in soil, with the effects of pedological factors such as soil drainage status and parent material and with the problems arising from trace element deficiencies and excesses.

In conclusion, I should like to express my sincere thanks to the President, Council and Members of the Naturforschende Gesellschaft for inviting me to address them on Soil Research in Scotland. This is an honour which I greatly appreciate.