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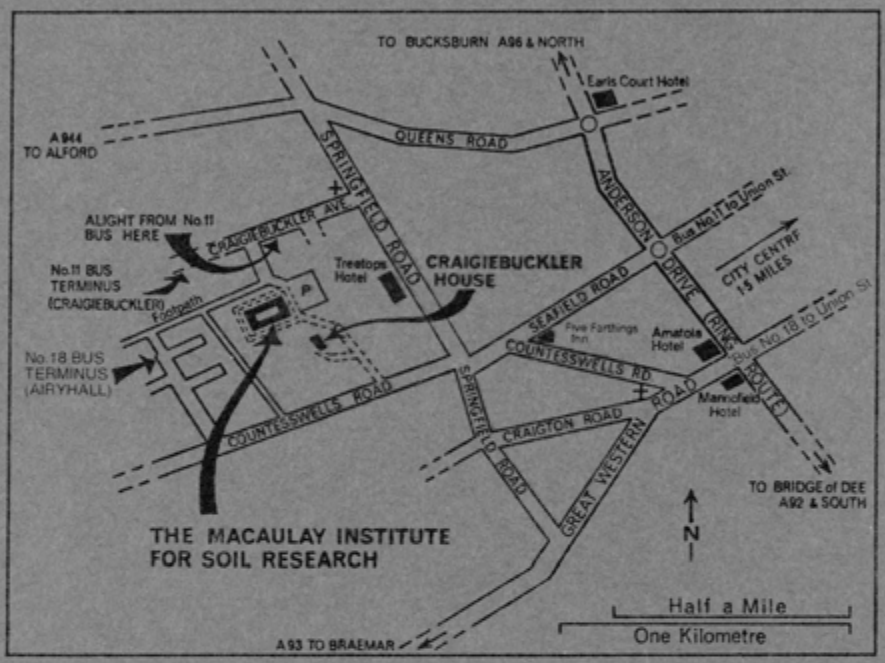

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The main part of this report covers the period from 1st October, 1981, to 30th September, 1982. The staff list is that current in November×December, 1982, and the Introduction is similarly updated. The report was published in May, 1983.

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THE MACAULAY INSTITUTE FOR SOIL RESEARCH

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CONTENTS

INTRODUCTION

T. S. West

The year 1982 has been a somewhat traumatic one for the Institute. It has been subject, as have all other ARS stations, to uncertainties regarding the future arising out of the need for the Agricultural Research Council to reduce staff numbers in its Institutes. The Scottish Agricultural Stations have not had to face such direct measures as those in England and Wales, but the consequences of upheavals in the south are inevitably felt in Scotland. Staff numbers have been reduced in most Departments of the Institute due to two factors, the necessity imposed by DAFS for a small percentage reduction in the salary budget and the retirement of several senior members of staff upon reaching their sixtieth birthdays. In January, 1982, the Institute had its scientific programme reviewed by an ARC Group and the Report to DAFS was not seen by the Institute until the Autumn. The vacancies created by the retirement of senior staff were, therefore, kept open until DAFS had discussed it's and the Institute's reactions to the Programme Review Group's recommendations and decided on an acceptable course of action. This combination of factors and the general unease felt about the employment situation in Britain has, therefore, not created an atmosphere particularly conducive to initiating and conducting good research in 1982. The consequences of this may be felt in subsequent years rather than now; nevertheless, it is heartening to be able to report extremely good progress during the year with 104 papers published as opposed to 80 and 92 in 1981 and 1980, respectively. In addition, substantial progress has been made in solving several practical agricultural problems as well as in strategic and basic research work and the work of two senior members of staff has been recognised by the award of DSc degrees from the Universities where they first graduated. The work of other members of staff has also been recognised publicly by different awards.

In the previous report[1] attention was drawn to the widespread occurrence of blockage of field drains by iron ochre and a map was produced indicating some of the problem areas[2]. The work being done in the Department of Mineral Soils to study the mineralogical nature of the ochre was discussed[3, 4] and the probable involvement of the microbial population of the soil in ochre production. The expertise of the Departments of Soil Organic Chemistry, Soil Survey and Soil Fertility has also been involved in our study of this very practical agricultural problem which creates great difficulties for farmers. During the year, joint investigations into this problem have again involved these departments and it can now be reported that a great

deal of progess has been made towards finding an ameliorative measure which appears to be both effective and inexpensive in practice. The blockage by ochre arises by the solubilization of iron from soil upon reduction to its lower (Fe II) oxidative state. Subsequently the iron is oxidised again (Fe III) within the drainage water by chemical/biological oxidation processes. At the level of acidity of most drainage waters the oxidised iron is hydrolysed and, therefore, forms voluminous deposits of poorly ordered hydrated iron oxides which probably age to goethite, the principal iron oxide component of ochre. We have now been able to show in the laboratory that large amounts of iron (Fe II) can be removed from solution by tannins and other insoluble phenols such as those that are known to be present in the bark of many trees. This has led to field experiments, see Section 4, in which sacks of aged bark of readily available coniferous trees have been placed in strategic positions in field drain systems where the drainage water can readily pass through and over them. Initial results obtained from several sites over a period of six months have shown a great deal of promise. In all the problem areas tested so far, drains where sacks of bark have been deposited have shown little or no tendency to blockage, whereas neighbouring ones have shown the usual phenomenon.

Furthermore, the tannins and phenols do not appear to be appreciably released into the drainage water so that the process appears to be environmentally acceptable. The labour involved in placement of these sacks and recovering them for inspection or in changing them after a period of months is small. So far, the sacks have been placed in the readily accessible inspection pits of several drainage systems and it is probable that this may be the best way in which to utilise this preventive system in the future. Further work is in progress.

Effects of Organic Matter on Soil Structure and Plant Biochemistry

Gardeners and farmers well recognise that the presence of organic matter has *inter alia* a beneficial effect on soil structure and physical properties, *e.g.* in soil that has been under pasture for some time. Within the past few years a good deal of attention has been paid to this aspect of the role of organic matter in improving soils as media for plant growth. During the year under report, see Section 4, the role of carbohydrates in stabilizing soil aggregates has been shown to be a most important factor. This has been demonstrated by comparing aggregation before and after the treatment of soil for various periods with a chemical agent which destroys carbohydrate. A significant positive correlation was obtained between the residual sugar content and the water stability of the soil micro aggregates, suggesting that much of the structural stability is attributable to the carbohydrate.

Organic matter in soil also influences the growth of plants by *inter alia* affecting biochemical processes in the tissues of different plants in various ways. For example, during the year it has been shown that humic acid inhibits the formation of the amino acid hydroxyproline in the cell walls of pea roots, whereas in beetroot storage tissue the reverse is observed. Humic

acid increases the activity of a number of plant enzymes and in the storage tissue it probably acts by stimulating the one responsible for the hydroxylation of proline.

Microbial Fertilizers

During the year we have continued to study the influence of soil microorganisms on the transfer of nutrients to plant roots in the soil, see Section 6. It has been shown that a wide range of agricultural plants can obtain both their nitrogen and phosphorus requirements from large inocula of microbial cells almost as readily as from inorganic nutrients. This has potentially important implications for the utilization of many waste products for fertilization of plant growth following microbial attack. Similar work is now being undertaken on the contribution to plant growth of the nutrients retained in the natural microbial community of the soil. These particular investigations are, of course, also aimed at providing a better understanding of the action of microbial and inorganic fertilizers in the soil.

In previous reports[5, 6] the action of lichens in the weathering of rocks and minerals has been studied and shown to be due to the secretion of oxalic acid by the lichens. The latter are associations of fungi and algae. It has now been shown that a large number of soil fungi belonging to the widely occurring genera *Penicillium* and *Aspergillus* can, and do, release oxalic acid and may, therefore, play an important role in the release or mobilization of soil reserves of important plant nutrients, thus further underlining the important role played by the microbial population of the soil in plant nutrition.

The Department of Microbiology has worked out a technique for characterizing the three dimensional arrangement and continuity of soil pores to explain the relationship of the activity of protozoa to the nature of their environment. This achievement should have considerable implications for work on the diffusion of gases in soils as well as the movement of plant nutrients and water.

Nitrogen Fertilization of Winter Barley

Work described in Section 7 relates amongst other things to practical problems now arising from the widespread growing of winter sown barley. Work during the year under report has shown that the crop needed high spring dressings of nitrogen to obtain optimal yields in the relatively dry 1982 season. Dressings of up to 200 kg ha^{-1} were necessary which, in one instance gave a yield of over 10 t ha^{-1} of grain (15% moisture content). Experiments also revealed that early sowing of the crop may not be so obligatory as has generally been thought hitherto inasmuch as the penalty of lower yield associated with late sowing may be overcome by using higher dressings of nitrogen in the spring. The effects of weather on soil conditions at drilling and crop establishment will, however, alter the pattern from year to year and this factor must be further studied.

Manganese Deficiency

There have been numerous reports of manganese deficiency symptoms in cereals in recent years. Studies of the problem have shown the

importance of the soil-root interface in relation to nutrient availability. Changes in pH and consequently manganese solubility in the rhizosphere soil during the growing season have explained why combine drilling of fertilizers is so effective in overcoming manganese deficiency in the spring barley crop.

Behaviour of Different Forms of Insoluble Phosphate

There has been considerable interest in Scotland on problems associated with phosphate supplies for certain crops such as Swedish turnips and grass land on our relatively acid soils as described in an earlier Report[7]. In many cases the need is met by partial use of insoluble sources such as ground mineral phosphate which gradually dissolve in the soil. It is in practice, more convenient to add granular or chipped forms of the insoluble phosphate rather than the powdered form but, particularly for Swedish turnips, the phosphate availability is much inferior.

Increased Yields from Sulphate Fertilization

Experiments conducted during 1982 have again confirmed, see Section 7, that increased yields can be obtained by sulphate fertilization in the relatively unpolluted area of northern Scotland, particularly for sensitive crops such as brassicae and grasses where the atmospheric input of sulphur is low and on " sandy " soils low in clay and organic matter which show poor sulphate retention capacity.

Important Development for Trace Elements in the Overall Soil-Plant-Animal System

The publication of the SARI/COSAC advisory bulletin on Trace Element Deficiency in Ruminants[8] constitutes an important development both in collaboration between the Scottish Agricultural Research Institutes and the Colleges of Agriculture and in collating the large amount of data on trace elements that has been accumulated by the different bodies over the years. Apart from its practical utility to the farming community, the bulletin should serve as an excellent springboard for new research into the extremely complex subject of trace elements in the soil-plant-animal system, particularly where it shows up areas of uncertainty or lack of knowledge.

Anomalies in Soil Acidity

The release of soluble aluminium from soil under acidic conditions is a predominant factor in growth inhibition on acid soils. Work described in Section 7 shows how a rigorous study of aluminium release by neutral salts from some acid clay soils has explained a puzzling anomaly in the determination of the cation exchange capacity of these soils. It was particularly gratifying to find that the pattern of Al release by different salts from different horizons is understandable in terms of the detailed mineralogy of the soil clays, showing once again the importance of basic knowledge of the physics and chemistry of soil components in order to rationalise soil behaviour.

Decrease in Application of Phosphate, Potash and Lime in Scotland

Following the processing of all advisory analyses in the North of Scotland area by the Institute's soil (fertility) data bank, it is possible to monitor nutrient levels in soils systematically. As suspected earlier, 1982 has shown a continued decline in the lime, phosphate, and potash status of soils in the area. There is probably a fair margin of safety still arising out of soil reserves built up by greatly improved farm management practices since the second world war. There is little doubt that the decline in fertilizer application stems from worsening economic conditions in the agricultural industry. However, it is inevitable that yields will decline if the lime and the P and K nutrient levels of our soils are allowed to decrease much further.

1:250,000 Scale Soil and Land Capability for Agriculture Survey of Scotland

The project to produce sets of soil and land capability for agriculture (LCA) maps at the 1:250,000 scale for the entire land mass of Scotland is nearing completion and publication is anticipated early in 1983. The seven soil maps have been printed and the corrected colour proofs of the corresponding LCA maps have been returned to the Ordnance Survey for printing. At the time of writing, four of the seven accompanying descriptive booklets are in press or at the final editing stage and the remainder are in advanced stages of preparation. All these publications will become available in 1983.

The new monograph describing the new revised LCA assessment scheme is in press and will be published in December, 1982. The system has been accepted as *the* official land classification system for Scotland and much of the Soil Surveyor's future effort will be directed towards its application. The new system[9] uses virtually the same seven classes as previously, but class 3 — *Land capable of producing a moderate range of crops* — is subdivided into Division 1 — land capable of producing high yields of a narrow range of crops, *e.g.* cereals and grass and moderate yields of other crops, and Division 2 — land capable of average production but possibly high yields of grass with greater restriction for some cereals. Class 4 — *Land capable of producing a narrow range of crops* — is subdivided into Division 1 — land suitable for rotation with good yields of grass involving difficulties of utilisation or conservation and below average yields of other crops, and Division 2 — land primarily suitable for grassland with rather limited potential for other crops. Class 5 — *Land capable of use as improved grassland* is subdivided into three Divisions — suitable — moderately suitable — marginally suitable for reclamation and Class 6 *Land capable of use only as rough grazing* is also divided into three Divisions — high — moderate — low grazing value. The new 75-page monograph is accompanied by a 1:625,000 scale Map of Climatic Guidelines for Scotland and presents detailed information of a classification based on soil,

climate and relief in a form which will be of value to land use planners, agricultural advisers, farmers and indeed all who may be involved in making the best use of land resources. The finer tuning of the LCA system should offer improvements over the former LUC one.

Heavy Metals from Sewage Sludge Dumped on Agricultural Land

There is considerable pressure from the water purification authorities for the dispersal of sewage sludge on arable soils and grassland where its fertilizer content may be of benefit. At the present time most of the dumping in Scotland takes place in the midland valley and around the conurbation of Edinburgh and Glasgow and it is probable that economic considerations will restrict intense distribution elsewhere. Many urban sludges have insufficiently heavy metal contents to constitute a serious worry in relation to heavy metal contamination of soils and, from them, crops and grazing livestock, but this is not always the case. In England and Wales the Department of the Environment has laid down guidelines for the maximum concentrations of toxic metals that may be added to agricultural land over a period of years. In Scotland the Colleges of Agriculture have published, with advice from this Institute, similar guidelines that in general would permit only lower levels and rates of application. Legislation is expected from the EEC in 1983 and the House of Lords Committee dealing with such matters has sought for a submission of views from the Institute. It is obviously important that the heavy metal content of the surface horizons of soils should not be irreversibly increased above acceptable levels by the dumping of sludges which at best can only have a transient nutrient value. However, the problem of monitoring, recording and controlling levels in sludges to be applied and subsequently the total contents of the surface horizons and of availability to and uptake by herbage and crops grown on such land for a period of years thereafter, together with surveillance of animal nutrition problems is an enormous one that will require not only enforceable legislation, certification and inspection, but also the devising of suitable analytical procedures, particularly for the sludges.

A survey of previous annual reports of the Institute shows that we have been monitoring soils and crops grown on sludge-treated land for a considerable number of years. Last year[10] the persistence of metals in an acetic acid extractable form in soils treated with metal-contaminated sludges some 13 years after application was reported. Further analyses of EDTA-extractable metals carried out in 1982 have supported this finding. The determination of *extractable* metal contents is a useful measure of plant availability and relates closely, *e.g.* for Zn and Ni to the contents found in grass species grown on such soils. However, the accumulation of metals in topsoils or possible loss by leaching can only be monitored by the analysis of *total* contents rather than assessing the available fraction. For this reason, work this year has concentrated on assessing simple and reliable methods for determining *total* amounts of metals, particularly cadmium and zinc in sludge-treated soils. As will be seen from Section 3 an inexpensive and

simple aqua-regia digestion/refluxing procedure has been standardised for total amounts of the potentially hazardous metals Cd, Cr, Cu, Mn, Ni, Pb and Zn in sludge-treated soils.

Improved Trace Element Capability by Atom Trapping

One of the problems associated with determining trace elements in soil extracts and plant tissues is that they sometimes exist at levels which lie below the capability of even modern techniques of trace analysis to detect, let alone determine them. For this reason it is often necessary to pre-concentrate the trace element from the original material into a small volume of material so that its concentration in the sample submitted to the instrument lies at a level not only above the detection limit of the instrument, but at a level sufficiently high to permit it to be determined with a reasonable degree of accuracy. Sometimes this can be done by extracting the trace element from a large volume of aqueous solution into a small volume of an immiscible organic solvent by adding, say, an organophilic complexing agent. At other times the trace can be coprecipitated or scavenged from the solution on a small volume of an indifferent precipitate generated deliberately within the solution, or added to it. Recent work described in previous annual reports[11] used preconcentration on aluminium powder by a process of cementation to yield the sample in a form eminently suitable for direct examination by spark source mass spectrometry. Part of the problem with these preconcentration techniques is that they involve the use of chemical reagents which, at the trace level, may introduce significant contamination by the element being sought and that they involve transfer from one vessel to another which may lead to further contamination or, in some cases, loss of trace material by adsorption or exchange.

A new technique — atom trapping atomic absorption spectroscopy — has been devised in the Institute which introduces no additional chemicals or transfers from one vessel to another. It ingeniously uses the technique itself to do the preconcentration by simply interrupting the process. In conventional atomic absorption spectroscopy, solution samples are sprayed into a premixed flame. The free atoms formed at the base of the flame are propagated through the beam of a hollow cathode lamp within the flame gases. A constant density of atoms passing through the beam of the lamp at *ca.* 10^3 cm sec^{-1} produces a steady state absorption signal directly proportional, within limits, to the concentration of the element in the solution being sprayed. In the atom trapping technique devised in the Institute, a water-cooled silica tube is situated within the flame just below the beam of the lamp. Free atoms generated at the base of the flame are condensed or trapped on the cold (*ca.* 200°C) surface of the silica tube and are collected there for a period of seconds or minutes as required to build up a sufficient amount. When sufficient species have collected on the surface of the tube, the coolant water supply is cut off and the water in the tube is blown out by a blast of air. This allows the skin of the tube to warm up very quickly and within a few seconds a dense cloud of free atoms of the collected species passes transiently through the beam of the hollow cathode

lamp to yield a peak signal which, within limits, is proportional to the concentration of the element concerned in the original solution. The coolant water is then switched back into the silica tube and the next sample is sprayed into the flame. The silica tube normally withstands repeated cycles of cooling and heating over a hundred times, until the surface of the tube becomes etched, since the coefficient of thermal expansion of silica is very small.

The technique was originally developed from an academic[12] and subsequently strategic point of view[13, 14] but has the capability of determining many trace elements at concentrations of 1 part per billion parts of solution (1:1,000,000,000). So far, we have shown the technique to be useful for Ag, As, Au, Bi, Cd, Mn, Pb, Sb, Se, Tl and Zn and during the past year we have successfully applied it to the analysis of natural waters, sea water and soil extracts for the determination of several elements at levels not possible without the use of time-consuming preconcentration techniques that also demand a high degree of skilled attention by the operator.

A New Theory of Podzolisation

The reappraisal of the mechanisms of aluminium and iron transport in soils and of the formation of podzolised soil profiles consequent on the recent spectroscopic work in this Institute on the minerals allophane and imogolite[15] has now been extended to other than Scottish soils. As a result of consultations and discussions held by Dr V. C. Farmer on his extended visit overseas in 1982, the transport mechanism evolved in the Scottish situation can be seen to be generally valid for podzols from freely drained coarse parent materials in a wide variety of climates. It is noteworthy that the considerable advance in our understanding of these agriculturally important mechanisms arose in the first instance from a fundamental study of the structure and formation of what was then considered to be an obscure Japanese mineral — imogolite.

Tree-Soil Interactions and Nutrient Cycling

The long-term studies of nutrient cycling in pine and spruce have shown that, because of the progressive increase in the amount of nutrients cycling within the system, demands made by the trees on soil reserves are much greater when the trees are small than at later stages. The management implications of this are being explored by constructing a simulation model of the nitrogen control of growth in pine. In addition, the relevance of these ideas to deciduous broadleaved species has now been examined by preparing models of the variation in nutrient cycling with age in stands of alder and birch. For both species the pattern of nutrient cycling was revealed to be essentially similar to that found for pine. Indeed, in fast growing alder, potassium demand on the soil was maximal as early as 2 years, but by age 4 had fallen to a fifth of this amount and was then less than the likely rate of input of potassium in rain and intercepted aerosols.

Sludge Fertilization of Forests

In co-operation with the Forestry Commission, the Water Research Centre and Tayside Regional Council, the Departments of Peat and Forest Soils and of Spectrochemistry have started an investigation into the likely nutritional benefits, and any harmful environment effects, of the application of liquid sewage sludge to an established stand of Scots pine. Should the environmental effects, such as contamination of neighbouring water courses or accumulation of heavy metals, be tolerable, spraying into forests could be a convenient means of sewage disposal from rural communities, with the prospect of considerable nutritional benefit to the trees. Also in collaboration with the Forestry Commission, a series of experiments has been carried out to investigate the use of dilute liquid fertilizers in forest nurseries, and it has been shown that these can offer the nursery manager considerable increased flexibility.

Acid Rain

In collaboration with scientists from the Swedish Agricultural University, Uppsala, an examination has been made of the relative roles of forest growth and rainwater acidity in the acidification of soils and streams. It was concluded that uptake of excess cations by trees will acidify soil but, because there is no concomitant movement of an anion, this will not result in loss of acidity into drainage water. Rainwater acidity, by contrast, is generally accompanied by the mobile sulphate anion, arrives in markedly episodic events and may pass rapidly into streams. The suggestion that trees in some way facilitate the movement of rainwater acidity into streams is being investigated in a range of experiments across the country. These reveal that, whereas at relatively unpolluted sites pH of rain collected beneath the tree canopy is consistently greater than that of incident rain, at pollution sites the neutralization process appears to break-down in mid-winter, leading to episodically high inputs of acidity to the soil. The suggestion by some German workers that such acidity may mobilize sufficient soil aluminium to destroy tree roots is being investigated in glass-house experiments. Preliminary evidence indicates that critical aluminium levels are unlikely to be encountered in Scottish soils at current rates of acid input.

EVENTS AND PEOPLE

Seventh T. B. Macaulay Lecture

The Seventh T. B. Macaulay Lecture, entitled " The Boundary Markers of Soil Science," was delivered by Professor J. Tinsley, FRIC, FRSC, FRSE, formerly Professor of Soil Science of the University of Aberdeen in the Marine Suite of the Amatola Hotel on 26th November, 1982. The lecture, which is presented as Appendix I to this Report, was very well attended by University staff as well as members of the Council and staff of the Institute and gave an excellent and skilfully proportioned prospect of

the history of the subject in the U.K. and with particular reference to its development in Aberdeen. The Chairman of the Council of Management, Professor T. C. Phemister, took the chair and the Director gave the vote of thanks and presented the Scroll of Honour to Professor Tinsley.

Dr R. L. Mitchell, 1910-1982

It is with very great regret that I have to record the death of Dr R. L. Mitchell on 7th February, 1982. Dr Mitchell had been associated with the Institute since 1931, first as an ARC research student — one of the first — then as a member of staff and Head of the Department of Spectrochemistry. In 1955 he became Dr D. N. McArthur's Deputy Director and in 1968 he succeeded Dr A. B. Stewart to the Directorship, a post which he held with distinction until 1975, when he retired and became one of the first Honorary Fellows of the Institute, the others being his predecessors, Sir William Ogg and Dr A. B. Stewart.

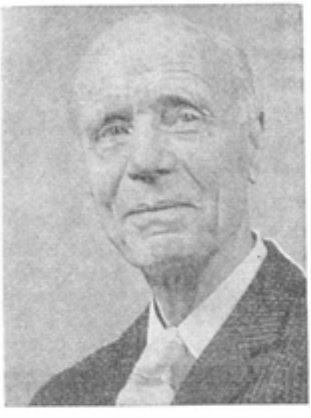
Dr Mitchell was a graduate of the University of Edinburgh and in 1963 was awarded the Royal Agricultural Society's of England's Medal in recognition of his studies on the relationship of trace elements in soils and plants to plant growth and animal health. In 1975 he was awarded the 10th Gold Medal of the Society for Analytical Chemistry, the first occasion on which the medal came to Scotland or was awarded to a member of the agricultural research service although, subsequently, it has come twice to Scotland and on each occasion to the Institute. Dr Mitchell was almost a founder member of the Institute's staff and he had a profound influence on its development and in winning an international reputation for it. He himself was recognised by his peers as one of the world's leading spectroscopists. His life's work on trace elements in soils and plants and the evolution of spectroscopic methods capable of yielding the necessary sensitivity and selectivity for such studies is an outstanding achievement well recognised by all who had the privilege of being associated with him. His life-long colleague Dr R. O. Scott, who retired from the Institute's service in 1981, has paid tribute to Dr Mitchell in the Royal Society of Chemistry's Analytical Proceedings[16] with another account to follow in the 1983 Handbook of the Royal Society of Edinburgh. Both give an excellent account of his career. Dr Mitchell will long be remembered with respect and admiration. The Macaulay Institute owes a great deal to him.

Mr J. Munro, 1926-1982

The death in service of John Munro, Higher Scientific Officer in the Department of Soil Fertility, came as a shock on 13th July, 1982. Mr Munro came to the Institute from the Rowett Research Institute in 1958

and made an invaluable contribution to the work of his Department, particularly as a member of Dr Norman Scott's sulphur team. He will long be remembered by all of us who had the pleasure of being his colleagues. A tribute was paid to him by Dr B. W. Bache in the August, 1982, issue of Profile.

Professor T. C. Phemister, Chairman, 1902-1982



It is with great regret that I also have to record the death of Professor Phemister on 30th December, 1982. He had served as a representative of the University of Aberdeen on the Council of Management since 1942 and was our Chairman since 1957. During his quarter of a century as Chairman he was unstinting in his efforts on behalf of the Institute. He shouldered the responsibilities and difficult decisions of recent years as cheerfully as he did those of the good times of earlier years. He was meticulous in his attention to detail and his ability to foresee eventualities was of inestimable value to the Institute as was his profound knowledge of its history and development. He was a scientist of internationally recognised distinction; we were indeed fortunate to have him preside over our Council's business for such a long time. He was a great friend of this Institute; we will miss him greatly.

During the year there have been a number of retirements as follows: Mr A. Hall, Senior Scientific Officer in the Department of Plant Physiology, retired on 31st March, having joined the staff in 1948 when this department was originally set up.

Miss H. T. G. Donaldson, Cashier, retired on 31st May, having joined the staff in 1957 after nine years' service with the North of Scotland College of Agriculture.

Mr D. Laing, Principal Scientific Officer in the Department of Soil Survey, retired on 30th June after almost 31 years' service. Mr Laing was an honours graduate in Chemistry of Aberdeen University, his academic career being interrupted by army service in North Africa, Italy, Greece and Austria. On joining the staff he first worked in Ayrshire, then Kincardine and Angus before taking over the sheets for East Perthshire and Fife. His service with the Institute is marked by a series of fine maps which bear his name.

Mr E. L. Birse, also a Principal Scientific Officer in the Department of Soil Survey, retired on 31st July, having joined the staff in 1953, after spending two years at the Institute of Tropical Agriculture in Trinidad. Mr Birse was an honours graduate in Botany of Aberdeen University. Although he started his career as a surveyor, he became the Survey Ecologist and provided descriptions of the vegetation for the Memoirs. Mr Birse built up

an impressive body of data on the relationships between soils and plants which led to a number of publications on the classification of Scottish plant communities and which have brought considerable reputation to the Institute as well as to himself. He also produced a series of maps and pamphlets on the assessment of climatic conditions in Scotland, which will long be recognised as standards.

Mr W. Bick, Senior Scientific Officer in the Department of Soil Organic Chemistry, also retired on 31st July after 36 years' service. Since 1972 he had been responsible for running the amino acid analysis service provided within the Institute and was recently involved in commissioning the newest form of amino acid analyser based on reverse-phase liquid chromatography. A Member of the Translators' Guild, Mr Bick was regarded as the " official " Macaulay interpreter in German.

Mrs C. A. Morice, Scientific Assistant in the Department of Soil Fertility, retired on 31st July, having joined the staff in 1975. Mrs Morice had previously served the Institute from 1937-49 and again from 1951-52.

Dr P. C. DeKock, Head of the Department of Plant Physiology, retired on 30th September. He came to the Institute in 1953 from the Botany Department of Aberdeen University where he had served since 1948. Dr DeKock was a first class honours graduate in Botany and Chemistry of Capetown University and, as a Rhodes Scholar at Oxford, was awarded a D.Phil. for his work on phenolic oxidation in plants. Dr DeKock led his Department's work with distinction and he devoted himself to his principal field of research in later years — calcium deficiency disorders in plants, particularly in relation to nitrogen nutrition — with enormous energy and enthusiasm. His pioneering work in this area attracted a great deal of attention, including several distinguished critics, but it is a matter of great satisfaction that his theories and experiments progressively gained ground and found widespread acceptance in the past few years. Dr DeKock was elected as an Honorary Associate of the Institute upon his retirement.

Mr J. W. Muir, Principal Scientific Officer in the Department of Soil Survey, retired on 31st August, having served with the Institute for 35 years. Mr Muir was an honours graduate in Agriculture of Glasgow University and came to the Institute from the West of Scotland College of Agriculture where he had served on the staff for a short time. Mr Muir was virtually a founder member of the Soil Survey of Scotland and he played a considerable part in formulating the policies which have since proved so successful in our soil mapping and classification. His publications show his wide range of interests including, in addition to survey and classification, notable contributions to soil chemistry and analysis, *e.g.* his studies of the mobilization of iron in soil. His contribution to the work of the Institute is an enduring one.

Mr J. C. C. Romans, also a Principal Scientific Officer in the Department of Soil Survey, retired on 31st October, having joined the staff in 1948. Mr Romans, an honours graduate in Chemistry and Geology of Durham University, did his early surveying in Banffshire and the Borders and then moved to the Mearns and Angus, the Black Isle, Easter Ross and

finally upland Moray. The development of soil thin section techniques provided a fertile field for the study of genetic processes and his meticulous examination of hundreds of sections has led to a deeper understanding of soil formation and chronological sequence. As a result of his investigations on archaeological sites and buried soils, his advice and opinion on many aspects of Quaternary geology was widely sought.

Mrs M. L. Craik, cleaner in the Institute since 1961, retired on 30th September. Mrs Craik had served in the Institute as a laboratory assistant from 1939 to 1942 before her marriage.

Dr W. M. Crooke, Principal Scientific Officer in the Department of Soil Fertility, retired on 30th November, having been on the staff since 1949. Dr Crooke, an honours graduate in Chemistry of Edinburgh University, joined the staff of the Soil Survey initially, but transferred within a few months to Plant Physiology and subsequently to the Department of Soil Fertility in 1961. His early work in Plant Physiology related to heavy metal toxicity in plants growing on serpentine soils, but moved on to cation exchange capacity of plant roots following a post-doctoral year in Canada, 1955-56. Dr Crooke's more recent work on nitrogen uptake of barley and swedes and its relation to dry matter accumulation and yield made an important contribution to establishing critical levels of plant nitrogen at various stages of growth.

Dr A. E. S. Macklon, Principal Scientific Officer in the Department of Plant Physiology, has been appointed Acting Head of the Department, with effect from 1st October, 1982, on the retiral of Dr DeKock.

Visitors to the Institute

In April, Dr V. A. Kuznetsov, Institute of Geochemistry and Geophysics, Academy of Sciences, Minsk, USSR, visited the Institute, and in May we received Professor Z. Maksimovic, Faculty of Mining and Geology, University of Belgrade, Yogoslavia. Dr I. Michalik, Head of the Central Chemistry Laboratory of the University of Agriculture, Nitra, Czechoslovakia, came to the Institute, and in June and in August Dr G. R. C. Cooper, Head of Chemistry and Soil Research Institute, Zimbabwe, also visited us. Visits were made by various members of the staff of ARC and DAFS.

Other visitors who came to the Institute and delivered lectures were: Dr Murray B. McBride, Associate Professor in the Department of Agronomy, Cornell University, Ithaca, NY, USA, on " Trace Metal Bonding in Soil Colloids "; Dr R. Lee, DSIR Soil Bureau, Lower Hutt, New Zealand, on " Chemistry and Morphology of New Zealand Gleyed Podzols "; Professor Leo de Galan, Technical University, Delft, The Netherlands, on " Recent Development in Inductively Coupled Plasma and Zeeman Effect Atomic Spectrometric Analysis "; Dr R. F. Browner, Department of Chemistry, Georgia Institute of Technology, USA, on " Developments in Atomic Spectrometric Analysis "; Dr Norman Chen, International Fertiliser Development Corporation, Muscle Shoals, Alabama, USA, on " IFDC and Research on Rock Phosphate "; Professor J. Loneragan, Dean of the School of Environmental and Life Sciences, Murdoch University, Western

Australia, on " Translocation of Trace Elements — Relationship to Nutrient Supply "; Dr Lloyd Elliott, Department of Agronomy and Soils, Washington State University, Pullman, Washington, USA, on " Wheat Root Colonization and Crop Residue Decomposition."

Short-term visitors from 22 countries came to the Institute during the year and group visits included delegates from various conferences held in Aberdeen, *i.e.* Scottish Grassland Workers' Conference, OS Digital Mapping Seminar, Aberdeen Branch of the Scottish Association for Biological Education, WHO course on Environmental Impact Assessment, Grampian Region School Science Convention; a party of students from the Department of Soil Science and Geology (accompanied by Professor L. J. Pons), Agricultural University, Wageningen, The Netherlands, post-graduate and honours students in Soil Science, Biochemistry, Chemistry and Geography from the Universities of Aberdeen, Edinburgh and Glasgow and from the University of East Anglia, students from the North of Scotland College of Agriculture and pupils from local schools.

Long-term visitors were received from Argentine, Bangladesh, Canada, China, India, Italy, Newfoundland, New Zealand and the USA.

Honours and Appointments

Mr J. S. Bibby, of the Department of Soil Survey, has been appointed a Visiting Professor in Soils, Soil Survey and Land Use in the Department of Geography, University of Strathclyde, for a period of three years from September, 1982.

Dr J. W. S. Reith, Department of Soil Fertility, received the Royal Northern (Agriculture Society) and Press & Journal Shield for his distinguished services to agriculture.

Mr J. D. Russell, Department of Spectrochemistry, was awarded the degree of DSc of Edinburgh University for a thesis entitled " The Application of Absorption Spectroscopy, particularly Infrared, to the Study of Clay Minerals, Soil Organic Matter, Soil Additives and Related Compounds."

Mr K. W. M. Brown, Department of Statistics, was awarded the degree of MSc from the University of Wales for a thesis entitled " Cambridge Sheep Data-Base — Operational Aspects and the Development of a Selection Index."

Mr Lau Chau Ming, student in the Department of Spectrochemistry, was awarded the prize for the best lecture at the " Research and Development Topics " Meeting of the Analytical Division of the Royal Society of Chemistry at Hull in July. He described his research on atom-trapping atomic absorption spectroscopy and his PhD thesis on this topic was accepted subsequently by the University of Aberdeen.

Dr V. C. Farmer, Department of Spectrochemistry, was awarded a Research Fellowship by the Japan Society for the Promotion of Science to allow him to work in Japan for two months with Professor N. Yoshinaga in the Ehime University and with Professor K. Wada in Kyushu University. He subsequently visited and lectured in Australia, New Zealand and Canada.

Dr B. A. Goodman, Department of Spectrochemistry, was granted one year's sabbatical leave to work in the University of Illinois. Dr Goodman was awarded a Nuffield-Leverhulme Travelling Fellowship to the USA — the first member of SARI to receive this — and also a Senior Scientist Award from NATO.

Mr J. Mitchell, of Technical Services, was appointed as a member of the Scottish National Board of the Institute of Medical and Biological Illustration.

Dr B. W. Bache was appointed Secretary of the Aberdeen Institute of Ecology.

Dr R. C. Mackenzie received the Netzsch-GEFTA Award of the West German Thermal Analysis Society, Gesellschaft für Thermische Analyse e.V., at the 7th International Conference on Thermal Analysis at Kingston, Ontario, Canada, in August, 1982, being the first non-native-German-speaking scientist to receive this award. He was also presented with an engraved, mounted, brass plaque in recognition of his role in founding the International Confederation for Thermal Analysis and his services to that organisation.

Dr D. C. Bain has been appointed Honorary Secretary of the Philips X-ray Spectroscopy Users' Group, Scottish Section.

Mr B. F. L. Smith has been awarded the qualification of C.Chem.MRSC by The Royal Society of Chemistry.

Dr T. S. West was appointed to membership of the Royal Society's British National Committee for Chemistry as a representative of the Royal Society of Chemistry. He was also appointed to the International Relations Committee of the latter and elected as a member of the Council of its Analytical Division. Dr West also became a co-opted member of the Board of Governors of Robert Gordon's Institute of Technology and was elected Vice-Convener of the RGIT Finance and Policy Committee.

Visits Overseas by Staff, etc.

Details of visits overseas by staff and of UK meetings where lectures were given are presented in Appendices II and III respectively.

Postgraduate Students

Miss C. A. Flower, meantime working in the Department of Peat and Forest Soils on a one-year CEGB Contract, has been awarded an ARC Research Studentship which will commence in February, 1983. Mr M. J. Hepher and Miss S. G. Williams have now finished their experimental work for the degree of PhD and are currently writing up their theses for submission to the University of Aberdeen.

Institute Events

The Council of Management met twice, on 28th May and 26th November. The joint MISR/COSAC Consultative Committee on Soils met also in November and a number of formal working parties were set up including: Nitrogen Response Model, Soil Survey Literature, Advisory

Soil Analysis and Reporting, Soils Information Base, Trace Element Information and Maximum Yield/Yield Constraint Studies. Because of the rapid inter-departmental progress that has been made on the resolution or practical problems relating to the formation of iron ochre in field drains, an iron ochre task force has been set up under Mr B. M. Shipley of the Soil Survey to co-ordinate progress and work in the various departments. Several courses on Remote Sensing have been run by the Remote Sensing Unit of the Department of Peat and Forest Soils and the Department of Statistics has provided very successful courses of instruction for new computer users. The interest in using micro computers led to 60 applicants for a practical course in BASIC programming with " hands on " experience. The course is being repeated until all applicants have been trained.

The Institute exhibited some of the Soil Survey work in the DAFS Pavilion at the Royal Highland Show at Ingliston in June and also at the Turriff Agricultural Show and the Lorne Show later in the summer.

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

100	Pedology (Division)	500	Microbiology
200	Spectrochemistry	600	Soil Fertility
300	Soil Organic Chemistry	700	Statistics
400	Plant Physiology	800	Soil Survey

In addition to the research projects, a number of service projects are also listed. When these are non-departmental, provided by Technical Services or Administration, they bear a 900 series identification, while for inter-departmental services for which one department is responsible, the appropriate series number of that department is prefixed by 5. A list of service projects follows that of the research projects.

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PROGRAMME OF WORK

RESEARCH PACKAGES AND ASSOCIATED PROJECTS

PACKAGE 1: The study of the development and composition of mineral soils and their size fractions.

Objective: To elucidate the factors that control the composition and contribute to the physical and chemical properties of mineral soils. So to provide information that could help to explain differences in soil structure and soil behaviour.

(a) Characterization of Minerals and Major Constituents

Projects

101 Scottish soil types: chemical and physical characterization in relation to development.

103 Soil mineralogy: relationship with soil type and soil properties.

104 Minerals: alteration during weathering and soil development.

107 Mineral and organic soils: development of chemical and instrumental methods of examination.

108 Mineral and organic soils: characterization by products of thermal decomposition.

109 Mineral and biological materials: structure and composition by electronoptical and electron probe methods.

(b) Trace Element Characterization

201 Distribution and location of trace elements in soils: effect of soil parent material and drainage conditions.

204 Geochemical distribution and pedological behaviour of trace elements.

205 Development of techniques for the determination of trace elements: direct reading methods and computer processing.

206 Development of flame emission and atomic absorption methods: instrumentation and techniques for trace and major elements.

703 Development of computer techniques and programs.

PACKAGE 2: The study of the nature and surface properties of soil clay minerals and mineral-organic matter complexes.

Objective: To investigate the factors involved in the surface and colloidal reactions of soil minerals, particularly of the clay minerals and complexes that participate in the mobilization or binding of plant nutrients in the soil.

Projects

105 Soil colloids: nature, origin and behaviour of inorganic, organic and organomineral complexes.

106 Surface characteristics of soil particles.

207 Characterization of soil minerals and study of their surface properties and weathering by infra-red methods.

304 Nature, distribution and properties of humic soil substances.

PACKAGE 3: The survey and classification of the mineral soils of Scotland.

Objective: To map and classify soils systematically according to their parent materials, pedological drainage and other field characteristics: to produce land use capability maps. The systematic survey identifies soil types and facilitates other investigations of the cause of differences in their fertility and other soil properties.

Projects

801 The systematic survey of Scottish soils.

804 Studies of soil structure and genesis.

PACKAGE 4: The study of the nature and properties of soil organic matter.

Objective: To determine the nature of the organic materials in soils at different stages of decomposition under different pedological conditions and to ascertain their contribution to the physical structure and chemical behaviour of soils and their effect on the growing plant.

Projects

208 Characterization of soil organic matter by infra-red and ultra-violet methods.

303 Nitrogenous constituents of soils, peat and leaf litter, relationships with co-occurring macromolecules.

305 The synthesis and degradation of polysaccharides and related constituents of soil organic matter.

307 Characterization of soil humic substances by means of their paramagnetic properties.

309 The effect of organic constituents of soil on the growth and nutrition of plants, with particular reference to processes involving the root.

311 The effects of organic constituents of soil on biochemical processes in plants.

PACKAGE 5: The investigation of the role of soil microorganisms in soils and in soil-plant relationships.

Objective: To assess the effects of soil microorganisms in the breakdown of organic material in soil and to study the interactions between soil microorganisms and plants in order to ascertain the nature of their contribution to crop growth and yield.

Projects

301 Chemical and biochemical investigations of organic material of microbial origin.

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

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

510 Investigation of soil protozoan populations.

512 Microbial degradation of soil organic matter.

513 Interrelationships of soil actinomycetes, bacteria and protozoa with plant-roots.

514 Asymbiotic nitrogen fixation by soil microbes in the rhizosphere of agricultural plants and in peat.

515 Survival of fungi in soil: their degradation and transformation into soil organic matter.

516 Interrelationships of soil fungi and their metabolites with plant roots.

PACKAGE 6: The study of the nature and distribution of organic soils and peat in Scotland.

Objective: To survey and classify the peat deposits and organic soils in Scotland and to study their utilization and potential fertility for agriculture, horticulture and forestry.

Projects

110 Organic soils: moisture retention and root development.

111 Organic soils: site capability and amelioration.

112 Scottish peat deposits: survey, classification and characterization.

114 The use of peat and peat products in agriculture and horticulture.

116 Nitrogen mineralization: factors controlling release of nitrogen immobilized in peat and humus

118 Developing of remote sensing methods.

119 Photogrammetric mapping applications and digital image processing of remotely sensed data.

120 Contractual applications of remote sensing for natural resource surveys and environmental monitoring.

PACKAGE 7: Investigations on the fertility of soils and the yield of agricultural crops.

Objective: To investigate factors controlling, and to study means of improving, the fertility of agricultural soils by related field, pot and laboratory studies on soil nutrient status, fertilizer usage and crop yield.

(a) Soil-Nutrient Relationships

Projects

203 Forms of occurrence of trace elements in soils and the mechanism of their movement towards the plant root.

317 The nature and properties of organically bound phosphate in soils.

601 Inorganic soil phosphorus and sulphur: evaluation of available forms and effects of fertilizers.

602 Organic phosphorus and sulphur in relation to soil type and nutrient supply.

603 Available nitrogen in soils.

604 Soil acidity: aluminium solubility and cation exchange equilibria in different soil types.

605 Anion sorption: kinetics and equilibria of phosphate reactions in relation to soil composition.

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

614 Electrochemical studies on soil-nutrient-plant relationships.

(b) Soil-Plant Relationships

607 Growth, development, nutrient accumulation and yield of field crops: effects of environment and management.

608 Field responses to nutrients: soil type effects and prediction of fertilizer requirements.

609 Trace element status of soils and crops: effects of soil type: diagnosis of deficiencies and excesses.

610 Assessment of lime and nutrient status of soils.

612 Soil physical conditions and crop growth.

701 Theory of experimental design and statistical analysis.

702 Relationship of crop yield and composition to soil properties, and the numerical classification of soils.

PACKAGE 8: The study of factors affecting crop composition.

Objective: To investigate the effects of soil conditions on crop composition and to study plant-physiological aspects of soil-plant relationships. The content of the plant and its individual parts may have particular reference to soil-plant-animal problems related to both major and trace nutrients.

Projects

202 Trace element uptake by plants: distribution in different species and plant parts.

401 Iron and copper metabolism of plants.

402 Uptake and physiological effects of chelated trace elements on plants.

407 Salt absorption: physical and metabolic aspects.

408 Nitrate reductase and molybdenum-copper interactions in plants.

606 Inorganic and organic constituents in crops: forms, patterns and balance in relation to age and yield.

613 Development and application of radioisotope techniques.

PACKAGE 9: The study of the fertility of forest soils and other non-agricultural soils and their natural vegetation.

Objective: To study the nutrition of conifers and other non-agricultural crops on forest soils, peats and other soils of limited capability. To study the natural vegetation in relation to soil type and to consider means of improving the utilization of marginal land.

Projects

115 Conifer nutrition: nutrient cycling, tree growth and influence of fertilizers.

117 Nutrient deficiencies in conifers: diagnosis and amelioration.

802 Plant communities and their relation to genetic soil types.

A research grant from the Forestry Commission contributes towards the cost of the forest soil projects.

SERVICE PROJECTS

Non-Departmental

Projects

901 Provision of Instrument Workshop facilities.

902 Provision of Photographic facilities.

903 Provision of specialized materials and equipment.

Departmental

Projects

5107 Mineral and organic soils: application of chemical and instrumental methods of examination.

5205 Application of techniques for the determination of trace elements: direct reading methods and computer processing.

5206 Application of flame emission and atomic absorption methods for trace and major elements.

5313 Provision of analytical facilities employing special equipment.

5314 Supervision and maintenance of general glasshouse facilities.

5613 Provision of radioisotope facilities.

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

5703 Data preparation and computer processing.

1. MINERAL SOILS

R. C. MACKENZIE and B. D. MITCHELL

R. C. Mackenzie.

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In accordance with the general aim of the work of the Department — namely, to obtain a better understanding of the factors that control the formation, composition, constitution and properties of mineral soils in Scotland and hence determine their inherent fertility — studies during the year have progressed along the lines previously established. These involve physical and chemical characterization of mineral and organic components.

A mineral soil in the field represents an extremely complex solid-liquid-gas system in what might be termed a pseudo-equilibrium state, the actual position of equilibrium being determined by both external (e.g. climate, vegetation) and internal (e.g. moisture, pH) factors. The liquid and gaseous phases, as represented by the soil solution and the soil atmosphere, are undoubtedly the most subject to alteration with change in external or internal conditions, but it cannot be assumed that the solid phase is exempt from effect. Thus, the solid phase normally consists of an extremely intimate mixture of animal, vegetable and mineral matter, the animal and vegetable being both living (e.g. microorganisms, worms, roots) and dead (humus) and the mineral ranging in order from highly crystalline to gel-like. Moreover, organomineral complexes or compounds also occur. Clearly, therefore, the very act of taking a sample, let alone the air drying and sieving procedures customary before laboratory examination, ensures that the soil examined in the laboratory is not identical with the soil as it occurs in the field. Yet results obtained in the laboratory, even if they cannot be directly extrapolated to field conditions, enable comparative assessments to be made.

The type and magnitude of the changes that occur during sampling, drying (whether in the field or the laboratory), preparation for laboratory examination, or even compaction by heavy farm implements, depend on the nature of all three phases in the soil, but insofar as the solid phase is

concerned, undoubtedly reflect the composition, structure and properties of the surfaces of soil particles, whether these be inorganic, organic or organomineral. Consequently, if the behaviour of the soil in the field and the manner in which laboratory results might be extrapolated to field conditions are to be properly understood, a detailed knowledge of the nature and characteristics of these surfaces and of the changes that occur on drying out, aggregation, compaction, etc., is essential. With its experience and expertise in mineralogy and physical chemistry, the Department is in a particularly favourable position to make major contributions in this direction and one could, indeed, now modify the title of project 106 to read "Surface characteristics of soil properties in relation to soil structure and soil tilth".

During the year, the specialized facilities and expertise within the Department have been utilized by various outside bodies including DAFS, the National Coal Board, the Rowett Research Institute, some Regional Councils and several companies connected with North Sea oil exploration and production.

Soil Analysis

Chemical Studies. Systematic chemical and physical tests on all profile samples collected by the Soil Survey of Scotland in the 1981 field season have been completed. Profile samples have also been examined for other departments of the Institute and for outside bodies, such as DAFS, NCB, Dumfries and Galloway Regional Council. Work has continued on the input of data into the Institute's Soil Data Bank, priority being given to National Soil Inventory profiles: data for about one quarter of the latter have now been entered. 101, 104, 204, 207, 801, 5107

There has been an increase in the number of samples of herbage analysed for sulphur by X-ray fluorescence spectroscopy at the request of the Department of Soil Fertility and the Rowett Research Institute. A new low-dilution technique of sample preparation for X-ray fluorescence spectroscopy has proved to be useful by reducing determination time and increasing sensitivity, so that sodium and some trace elements can be determined in addition to the usual major elements. This has been successfully used in the analysis of soils of widely varying composition, of weathering products and of minerals, such as saponite, chromium-rich volkonskoite and celadonite. X-ray fluorescence spectroscopy has also been used to check the validity of the results obtained for soil phosphate content by a new method employing sodium hydroxide fusion in nickel crucibles[1]. 101, 103, 104, 107, 601, 801, 5107

Methods based on chemical composition, on the nature and amount of poorly ordered aluminosilicate material present and on the degree of polymerization of silica after acid attack have been applied to a number of residual soil profiles developed on rocks that give rise to the major soil associations in north-east Scotland. Analysis of the results has shown that methods based on chemical data are most in accord with field evidence and that the amount of monomeric silica released on acid attack has an

overall significant relationship with the nature and amount of poorly ordered aluminosilicate material present, even although this relationship is not so well expressed in individual profiles[2]. Earlier studies on the value of trimethylsilylation in assessing the stability of minerals to acid attack have now been published[3]. Chemical analyses of Scottish soil profiles have been used to assess the eluvial/illuvial coefficients of major elements and the corresponding losses and gains of these elements in the various horizons: the results have been considered in relation to profile morphology and development[4]. In collaboration with the Department of Spectrochemistry, the effectiveness has been assessed of a number of techniques for chemical extraction of illuvial oxides of aluminium, iron and silicon from the B_3 horizon of a podzol: results lead to the conclusion that a knowledge of both organic and inorganic forms of these elements is necessary for a rational chemical classification[5]. 101, 104, 105, 207, 801

Further measurement of the major element composition of soil and stream water in catchment areas within seven principal soil associations in north-east Scotland have demonstrated that in six of the streams the aluminium content is always less than 0·1 ppm and the iron content generally below 0·2 ppm. In the stream in the catchment area of the Countesswells soil association, which is the most acid, the aluminium and iron contents are consistently greater than 0·2 and 0·9 ppm, respectively. 101, 105, 106, 107

Thermoanalytical Studies. Thermal analysis developed gradually from man's early interest in the effect of fire, or heat, on materials[6], but development has always depended on the technological status of the period[7]. Only recently has it been possible to devise internationally acceptable definitions[8] covering the many techniques now involved[9] and therefore to assess the earliest experiments that could be so designated[10]. The fact that the techniques tend to analyse for *phases* rather than for *elements*[11] can be useful in many studies, especially in soil science, where a knowledge of chemical composition is often of little value unless it is known how the elements are combined. Thermogravimetry (TG), differential thermal analysis (DTA) and differential scanning calorimetry (DSC) are undoubtedly the most common techniques and these have found wide application within the Department in both mineral and organic studies[12, 13, 14]. A recent assessment of the results of such studies has indicated that the soil, because of its complexity, provides an excellent model for assessment of the value of thermoanalytical methods in fields as diverse as geology, surface chemistry and polymer science and, indeed, in many intermediate[15]. 103, 104, 105, 106, 107, 5107

Interpretation, particularly quantitative interpretation, of results obtained by DTA and DSC can be time-consuming and, because of the wide range of thermal response yielded by different materials, can necessitate several determinations on the same material at different sensitivities. For this reason, all modern commercial instruments are provided with dedicated data-handling systems based on microprocessors—which are also sometimes used for temperature-programming. To overcome the absence of such

instrumentation, a data-processing system capable of taking the signals from all available thermoanalytical instruments is currently being constructed, using a recently acquired Apple II microcomputer and associated equipment. Early tests with a DSC instrument have proved encouraging. A two-stage high-stability DC amplifier, that enables coupling of the data-handling system to the micro thermobalance, has been designed and constructed with the aid of Technical Services.

101, 103, 104, 105, 107, 907

Soil Mineralogy

The natural process of weathering converts rocks to soils, releases plant nutrients through degradation of primary minerals and forms secondary minerals that can not only retain nutrients in forms available to plants but can also render them unavailable: these secondary (or clay) minerals, because of their small particle size and consequent large area of reactive surface, can have a disproportionate effect on soil properties. For such reasons there has, in the Department over the years, been much emphasis on studies related to the mechanism of weathering of various soil-forming minerals and to the nature of the products formed. One of the earliest stages of rock weathering is that attributable to lichens: indeed, the lichen-rock interface can be regarded as a micro soil profile within which chemical, biological, and even physical, aspects of rock weathering can be studied. In passing, it should be noted that, despite the distinctions frequently made between these three types of weathering, it is rarely, if ever, possible to attribute a natural alteration solely to one type or even to decide where one type of alteration ceases and another takes over. Work on lichen weathering, being prosecuted in collaboration with the Department of Microbiology, has been extended during the year to the investigation of lichen-encrusted rocks containing potentially toxic elements. Previous indications that the toxic effects of heavy metals could be evaded by their inclusion in insoluble extracellular deposits have been confirmed by the observation that the lead adsorbed on or into the hyphae of the lichen *Stereocaulon vesuvoinum*, growing on a lead ore, occurs in the form of the basic lead carbonate hydrocerussite[16] and that the excretion of oxalic acid by *Pertusaria corallina* growing on a manganese ore has led to the crystallization of zinc-substituted manganese oxalate at the lichen-rock interface. In these studies a combination of X-ray diffraction and scanning electron microscopy techniques with electron probe microanalysis has proved essential for interpreting mechanisms[17]. An assessment of the effect of lichen weathering on rock-forming minerals and of its implications for pedogenesis, based on such evidence, has recently been made[18].

103, 104, 109, 508

Scanning electron microscope, electron microprobe and optical microscope examination of soil thin sections has recently been successfully used to solve problems related to subjects as diverse as the nature of the cementation occurring within the illuvial horizons of some Scottish podzolic soils[19] and the characterization of Brazilian solodized solonetz soils.

Noteworthy in the latter is the accumulation of Ce, often associated with manganese accumulations. The same techniques are being used to study the morphological, physical and chemical differences that occur within a hydrological sequence of the Strichen soil association, particular attention being paid to the ochreous mottles and pseudo-concretions of manganese in the pseudo-gley and gley soils. 101, 109, 801, 804, 5107

Mineralogical information on Scottish soils, collected during systematic study of profiles supplied by the Soil Survey of Scotland, is currently being collated, coded and arranged in a form suitable for input to the Institute's Soil Data Bank. The data involved includes mineralogical information for the light and heavy separates of the fine sand fraction and for the clay fraction, quantitative for the former and semiquantitative for the latter. 103, 104, 801

Clay Fraction. The mineralogy and particle-surface characteristics of the clay fraction are particularly important in soil science because the properties of the minerals present vary over a wide range and, as pointed out above, can have a disproportionate effect on soil properties. In such studies the small size of the clay particles precludes the use of normal mineralogical techniques and a wide range of instrumental methods have to be applied, the indirect information thus obtained being integrated to arrive at something approaching the true position. Moreover, for correct interpretation of soil data it is necessary to examine pure minerals as well as soil clays from other localities. The study of the saponite from Orrock Quarry, Fife, referred to last year, has now been completed. It has been established that the fibrous material will swell with glycerol after mild chemical pretreatment or after a short period of grinding, presumably because it has a higher degree of structural order than the granular material and therefore interlayer water and hydroxide participate more fully in layer-to-layer bonding. The interlayer hydroxide material could not be detected by X-ray diffraction or infrared absorption spectroscopy but was revealed by thermoanalytical and chemical tests[20]. A full description of the filamentous illite, referred to in last year's report, has now appeared[21]. 103, 104, 107, 109

In order to characterize better the swelling hematite/layer silicate complex macaulayite, a study has been made of the reputed mineral melanosiderite which, because of its similar chemical composition, might be related. This material, in fact, proved to be a siliceous ferrihydrite[22]. A sample of the sulphate carbonate hydroxide mineral of lead, leadhillite, of ideal composition has been characterized by, *interalia,* X-ray diffraction techniques[23]. 103, 104, 207

Aluminium hydroxide occurs in three polymorphs, bayerite, gibbsite and nordstrandite, all of which occur naturally and which differ from each other only in the manner of superposition of the structural sheets. Collaborative studies with the Instituto di Chimica Agraria, University of Naples, on nordstrandite have shown that its crystal shape depends on the conditions under which it is formed[24] and that synthetic preparations

can contain small amounts of bayerite and gibbsite, sometimes co-crystallizing with the nordstrandite[25]. These observations suggest that great care should be exercised in interpreting data for aluminium hydroxide minerals in soils. 103, 104, 109

As previously, a number of soil clay samples from other countries have been examined for comparative purposes. Collaborative investigations with the Istituto di Chimica Agraria, University of Naples, have established that poorly ordered minerals such as imogolite, halloysite and a 12Å intergrade mineral in some Italian Andosols originated from the pedogenic weathering of primary minerals and volcanic glass[26]. Work on the chemical and mineralogical characteristics of some Turkish soils, formed under a semi-arid climate, has continued in collaboration with the Faculty of Agriculture, Cukurova University, Adana. These soils are quite different from the Italian Andosols in that they contain little poorly ordered material, the clay fractions consisting mainly of a smectitic mineral with an unusually high basal spacing. The widespread and *in situ* formation of the fibrous mineral palygorskite in wadi soils from Saudi Arabia has been established, in collaboration with the Faculty of Agriculture, University of Riyadh[27]. Soil clays from the Jordan Valley, a region of widespread market gardening, have also been examined in collaboration with the Faculty of Agriculture, University of Jordan, Amman. A communication, in collaboration with the London School of Hygiene and Tropical Medicine, regarding the possible role of clay minerals in the incidence of non-filarial elephantiasis of the lower leg in the population of Cameroon was presented at a joint meeting of the Clay Minerals Group of the Mineralogical Society and the British Occupational Hygiene Society. 103, 104, 105, 107, 109, 5107

Surface Characteristics of Soils and Soil Components

It has been demonstrated that iron is transported in the groundwater of a poorly drained alluvial soil as Fe(II) and that the combined effects of pH, Fe(II) content and soil texture lead to the precipitation of hydroxides at specific locations in the profile. The occurrence of an intensely ochreous mottled horizon at the peat-mineral interface is consistent with transport of Fe(II) in the groundwater by capillary rise. Although the predominant mineral in this horizon is goethite, the ochreous deposit in a recently installed tile drain consists mainly of the poorly ordered hydroxides ferroxyhyte and ferrihydrite and is identical with laboratory-prepared precipitates. Comparison of rate of oxidation of iron in the drainage water with that in a solution of similar concentration prepared in the laboratory suggests that neither organic components nor microorganisms may play a dominant role in the oxidative hydrolysis of Fe(II) in the soil solution. 101, 106, 107, 109, 801

In a poorly drained alluvial soil of the Stirling soil association, examined in collaboration with the Department of Soil Survey, a highly gleyed blue-grey horizon occurs at about 2 m depth. This appears to have been associated with a period of lush vegetative growth, subsequent anaerobic decomposition of the vegetation having resulted in the formation of black

microspheres of an Fe-S phase. The very low pH within the clay layer (2·5 has been recorded for a 1 : 1 solid : liquid suspension), combined with the high content of SO_4^{2-}, suggests a resemblance to the 'cat-clays' found in the Netherlands. 101, 106, 107, 801

Many poorly crystalline manganese oxides in soils appear to have a structure similar to that of the birnessite-buserite group with layers of octahedrally coordinated manganese ions and exchangeable interlayer cations. Replacement of the latter by alkylammonium ions causes expansion of the lattice and a standard method for recognizing buserite on this basis has been devised. Structural fractures appear to control cation selectivity: thus, buserite shows a marked selectivity for sorption of heavy metal cations and X-ray diffraction shows that even in solutions with a Mg : Ba ration of 200 : 1 the Ba-phase with a 7Å spacing predominates. 103, 105, 106, 107, 109

In some physicochemical measurements on soils and clays, results may be suspect unless an absolutely dry material is used initially. Removal of the last traces of water is, however, notoriously difficult, and such removal can greatly affect the original structure which it may be desired to retain. Recent investigations have indicated that critical point drying, whereby the water is first replaced with methanol, this in turn is replaced with liquid CO_2 and the liquid CO_2 is removed above its critical point, causes little, if any, disruption of structure, as judged from mercury intrusion porosimetry results, provided two days is allowed for exchange with liquid CO_2. Moreover, scanning electron microscope examination of soil clays so dried shows that the definition of individual clay particles is much improved. The kinetics of water sorption on soil components have also been examined[28]. 103, 106, 107, 109

Laboratory experiments carried out, in collaboration with the Department of Soil Survey, to determine the stability of silty clay soil samples from the Stirling soil association, with a view to predicting the likely life of mole drains installed in this soil, have revealed a low degree of stability. This accords with field observations of crusting and of the formation of a plough pan. 101, 106, 107, 801

Organic and Biological Materials

The analytical potential of the nature and abundances of the pyrolysis products derived from soil organic matter has already been considered[29] and work during the year has enabled the origin of all aromatic compounds, except benzene, detected in soil pyrolysis products to be established. It was earlier appreciated that 2-methoxyphenols originated from lignin residues and it has now been shown that toluene arises solely from phenylalanine and that phenol and *p*-cresol derive solely from tyrosine in peptides. Moreover, the nitrogen-containing compounds pyrrole and acetonitrile, the abundances of which are important in assessing degree of humification, originate solely from hydroxyproline and glutamic acid and from phenlyalanine, respectively, in peptide chains. These observations were made using a set of standard proteins, as well as individual amino acids,

and employing a new technique wherein polystyrene was used as an internal standard. The study of nitrogen-containing compounds has been extended to brown-earth humic acids and a paper on this subject was presented at the Fifth International Symposium on Analytical Pyrolysis, held in Colorado, USA, in September 1982. 108

Analytical pyrolysis of soil organic matter, previously used to characterize genetic horizons in soil profiles, has now been employed to distinguish morphological features within individual horizons. Thus, pale mottles within the AE horizon of a humus iron podzol have been shown to contain organic matter that is less in amount but more highly humified than that in the surrounding matrix; thin dark lamellae in the same horizon represent inclusions of less humified material from the overlying A_h horizon. As previously observed for this soil type, the organic material in the B_h horizon was similar to that in the AE but differed markedly from the illuviated material in the Bs. These conclusions were arrived at from an examination of the relative abundances of pyrolysis products characteristic of known biopolymers, as previously established by pyrolysis-mass spectrometry studies. 108

Analytical pyrolysis has shown that some soil profiles under oak woodland, examined in collaboration with the Department of Soil Survey, contain humus similar to that in brown earth and brown podzolic soils. As would be expected, the humus differs in character from that previously found beneath forest litter and in raw humus surface horizons. 108, 804

Capillary gas chromatography-mass spectrometry (GC-MS) studies using a direct GC-MS interface, carried out in collaboration with the Department of Soil Organic Chemistry, has enabled 68 partially methylated alditol acetates to be identified in repeatedly methylated soil extracts and has permitted the nature of the linkages in at least 70% of soil polysaccharide to be determined[30]. Other soil organic derivatives have also been examined by this method. All the above investigations, whether by GC-MS or by pyrolysis-MS, have been greatly facilitated by the new data handling system now in use with the mass spectrometer. 108, 303, 305

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2. PEAT AND FOREST SOILS

R. A. ROBERTSON

The work of the Department has continued to develop along the lines previously reported, emphasis being on the survey, evaluation and monitoring of peat, vegetation, crop and other terrain resources and on field, glasshouse and laboratory experiments designed to provide a better understanding of the biogeochemical factors and mechanisms controlling plant growth on highly organic and other marginal soils[1, 2, 3, 4, 5].

Acquisition during the year of additional equipment for ground survey operations and automated cartography has enabled the further development and application of remote sensing and photogrammetric techniques, particularly for peatland drainage and site preparation projects, and (at the request of DAFS) for monitoring and mapping the distribution and spread of bracken in Scotland. These developments together with advances in the processing[6] and interpretation of imagery derived from airborne and satellite sensing systems have been carried out in close collaboration with the National Remote Sensing Centre, Royal Aircraft Establishment, Farnborough, the Department of Industry (Space Division), the European Space Agency, the Scottish Development Department (Air Photo Unit) and Robert Gordon's Institute of Technology. In association with the Forestry Commission (Research and Development Division) substantial progress has also been made on studies designed to investigate the flux of nutrients and pollutants through different plant: soil systems, the object being to derive improved agricultural and sylvicultural practices that rely on manipulating natural cycles rather than on heavy inputs of fertilizer or energy and to enable assessment of the environmental consequences of any change in management techniques. Joint investigations with the Central Electricity Generating Board on the effect of atmospheric pollutants on plants, soils and natural waters have continued. An experiment to assess the effect of disposing sewage sludge on forest land has also been initiated, complementing similar work on agricultural land in the Department of Spectrochemistry.

The implementation and wider practical application of these and related developments have resulted in close and fruitful co-operation with other Departments within the Institute and with external organizations including the Highlands and Islands Development Board, the North of Scotland Hydro-Electric Board, the Peat Producer's Association, the Council for Applied Science in Scotland, the Scottish Agricultural Colleges, Grampian, Highland and Tayside Regional Councils, the Natural Environment Research Council, the Institutes of Hydrology and Terrestrial Ecology,

the Ordnance Survey, the Scottish Council (Development and Industry), the Universities of Aberdeen, Edinburgh and Dundee and the Water Research Centre.

Terrain Resource Survey and Monitoring Operations

Peat Survey and Evaluation. Survey, classification and evaluation of Scottish peat resources continue to provide a basis for research projects and advisory services related to peatland drainage, reclamation, afforestation and, increasingly, the production, processing and utilization of peat and peat products for horticulture[7], fuel and other industrial purposes. Remotely sensed data from ground, air and space and improved photogrammetric techniques are being increasingly employed in support of topographic and thematic mapping operations[8,9]. Results of these investigations are incorporated in appropriate Soil Survey Memoirs[10] and in more detailed reports for development and other agencies.

111, 112, 114, 115, 119, 120

At the request of the North of Scotland Hydro-Electric Board, the peatland survey of Shetland, initiated in 1981, has concentrated on the Island of Yell, the object being to locate and evaluate deposits that might be suitable for the production, drying and harvesting of air dry sod peat for the generation of electricity. A general peatland classification was first performed on Landsat imagery of 25th May, 1976, followed, prior to the commencement of on-site investigations, by the preparation of reconnaissance maps derived from 1:25,000 panchromatic air-photographs. Where available, true colour 1:10,000 aerial photography was also used to assist in locating peatland areas with apparent development potential. At the outset two types of deposit, basin/valley and blanket mires, were identified; each was later subdivided into three erosion categories. Ground truth surveys, depth sounding, acquisition of samples on a stratigraphic basis and other field investigations have now been completed and a report, incorporating the results of laboratory analyses, is in preparation. Eroded peatland is a particularly marked feature of the Shetland landscape and in many areas may mitigate against mechanical peat winning operations. Observations and measurements made during this year's field season suggest that, after prolonged drought, periods of heavy rain can result in the erosion and redistribution of between 0·53 and 0·74 cm of exposed peat surfaces.

112, 114, 119, 120

Sampling and assessment of Simonswood Moss, near Liverpool, has been undertaken on behalf of Merseyside County Council, the object being to establish the relative amounts of horticultural and fuel peat still available for commercial exploitation. A report has now been submitted[11].

112, 114

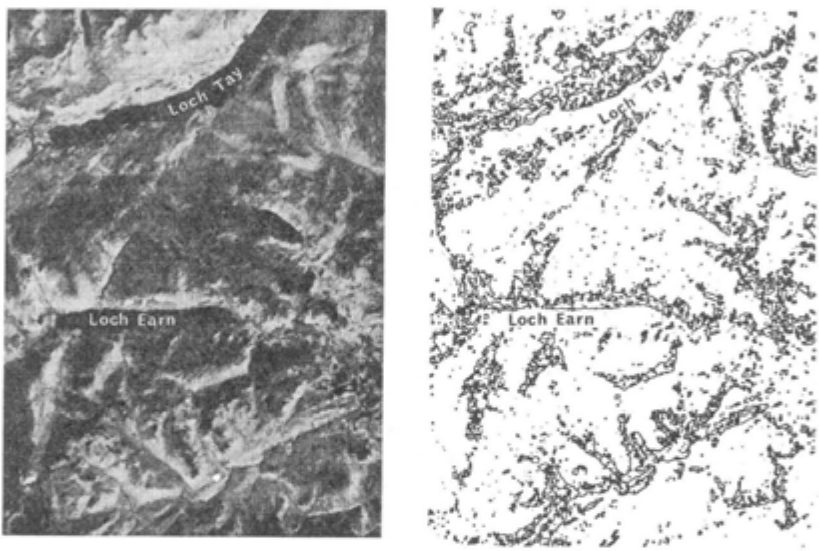
In collaboration with the Highlands and Islands Development Board, further progress has been made with the sampling and monitoring of the peat production project at Dale Moss, Caithness. In order to accelerate the provision of a large-scale working plan showing the present lay-out of

ditches, outfalls, access roads and the general disposition and area of each production unit, spatial and angular data recorded in the field using the new electronic theodolite were keyed into the updated photogrammetric system and converted to digitiser format. The relevant portion of the 1:10,000 Ordnance Survey map was then digitized and the two data sets scaled and integrated. The total time involved in field survey, data processing and plotting operations to produce a map at 1:1000 scale was a mere 7 hours. The working plan will now be used as a basis for studying and monitoring the relationships between field moisture conditions, initial output, rate of drying and volume weight of peat and yield of air-dry product. 112, 114, 119

Collaborative work with the Central Excavation Unit of the Scottish Development Department has continued at Strathallan, Perthshire[12]. Similar stratigraphic and palaeobotanical studies on peat and mineral soils being carried out in association with the Department of Soil Survey are providing useful information on environmental change and pedological processes and their relationship to past agricultural practices, particularly in the Lammermuir Hills. Using software developed by the National Vegetation Classification Unit at Lancaster University, a computer based analysis of over 200 peatland vegetation sites in Lewis and Harris has been completed. A paper on the seasonal growth of *Sphagnum* species has been published[13]. 112

Bracken Survey. A pilot study on the use of remote sensing techniques to map and monitor the distribution and spread of bracken in Scotland has been completed. The main objective of this study, initiated in 1981 at the request of the Department of Agriculture and Fisheries for Scotland, was to develop an appropriate remote sensing methodology and to evaluate the cost-effectiveness of the approach with respect to alternative mapping strategies. A test area, some 50 km by 50 km, was selected, extending from the Menteith Hills northwards to Loch Tay in the Central Highlands. Identification and delineation of bracken stands in sample areas during field and reconnaissance air surveys provided control information for the interpretation and photogrammetric plotting of actual bracken boundaries at scales of 1:7,500, 1:10,000 and 1:25,000 using multi-level aerial photography of the selected training areas. The resulting photogrammetric overlays of bracken distribution were then digitized and transformed from vector to raster form in grid cells of 50 m by 50 m on the ground which in turn were feature coded on a cover density basis ranging from 0-25%, 25-50%, 50-75% and 75-100%. This digital data set was then used to provide a supervised classification of Landsat multi-spectral imagery derived from a totally cloud free scene of the Central Highlands and rectified and resampled to the O.S. grid on 50 m picture elements. Next, a wide range of statistical classification procedures were tested using the high speed inter-active image processing facility (GEMS and IDP 3000) at RAE, Farnborough. The Institute's hybrid automated photogrammetric and image processing system (MAPIPS) was also used for the direct display and comparison of the controlled information, digitized in 50 m cells, and the

50 m classified Landsat pixels. A simple ratio of wavebands 5 and 7 (visible red/infra-red) was eventually found to provide a good fit of 4 reflectance ranges corresponding closely to the 4 rasterised cover densities. Results of this study show that bracken does have a unique spectral response at certain times during the growing season, especially near the end of August, and computer plots of its classified distribution have been produced at 1:100,000 and 1:50,000 scales (Fig. 2.1). The accuracy and statistical significance of these boundaries are still being assessed through field sampling procedures. If the success rate is high, this methodology will be applied to other areas in Scotland and eventually used to provide a bracken inventory of the whole country. 118, 119, 120



A B

Figure 2.1

Part of a Landsat satellite image of central Perthshire (A) recorded on 24 August, 1976, and subsequently corrected to fit the National Grid. The line map (B) shows the distribution of bracken predicted by a supervised classification of this image. The map was originally produced to overlay a 1:50,000 O.S. sheet.

Snow Monitoring. Following the earlier and successful use of Landsat satellite imagery for snow mapping in upland areas, a related aerial survey of potential skiing sites was commissioned by the Highlands and Islands Development Board. The first sortie on 4th April, 1981, was undertaken at the same time as a ground survey and only one day after a successful satellite overpass. This data is currently being analysed and a snow distribution map prepared. A further 12 aerial surveys, covering six sites in the Highland Region, were completed between December, 1981, and May, 1982. It is hoped that a CASE studentship to continue this work will be awarded in 1983. 120

Aerial Surveys. Apart from the dedicated aerial surveys related to the snow monitoring project and the AGRISPINE experiment, to be discussed later, a number of additional sorties have been flown during the year. For example, a strip of vertical stereo panchromatic photography at 1:20,000 scale was flown across the city of Aberdeen, parallel to the SAR 580 transect. The results will be used for an associated experiment to be conducted by Dr I. Dowman, University College, London, and to test the metric accuracy of the Hasselblad camera lens system, calibrated by University College for photogrammetric purposes. Other sorties acquiring 1:10,000 scale stereo panchromatic and infra-red false colour photography have been flown of a land drainage scheme west of Inverness, a peat development project in Caithness and of areas around Evanton and the Black Isle to monitor frost damage in winter wheat and barley crops. A large area of block 1:10,000 scale photography of Corlarach Forest has also been flown for the Forestry Commission. Final improvement to the camera rig by Dr W. H. Ekin, Robert Gordon's Institute of Technology, has resulted in the Civil Aviation Authority granting certification for its use on a Cessna 172 aircraft. 118, 120

AGRISPINE Experiment

The Space Informatics Network Experiment (SPINE) is an international project designed to demonstrate the high transfer rates of bulk digital data using the Orbital Test Satellite (OTS). In 1982, the AGRISPINE project was conceived as a suitable application for the SPINE facility, allowing participants to receive Landsat data in less than 24 hours for time-dependent studies. Applications currently being investigated by the Forestry Commission, MAFF, the Macaulay Institute, the National College of Agricultural Engineering and RAE, Farnborough include the monitoring of agricultural crops and forests in Grampian Region and in East Anglia, the calving of icebergs for a glacier in West Greenland and the characteristics of sea ice in the Gulf of Finland.

Since March 1982, test farms within the Laurencekirk area have been monitored at the precise time of Landsat overpass. On each pass date, both aerial and ground photography is acquired and records are kept of soil moisture conditions and the type, colour, height, growth stage, percentage cover and general condition of each crop. A more general crop map has been prepared for an 11 km by 2 km wide transect across the Mearns from Tod Head on the coast to west of Fordoun. Stereo, vertical and oblique photography has been acquired for the sample farms and complete video imagery in oblique mode has been obtained for the sample transect, test farms and forest areas being studied. During the year crop stress conditions, primarily due to the severe frosts last winter and to the severe droughts in May and June, were detected on Landsat imagery, video-film and colour infra-red aerial photography. It is likely that such conditions would have gone undetected without the timely transfer of space imagery through the SPINE link and the acquisition, at time of overpass, of aerial photography and ground survey data for precise correlation with individual fields. 118, 119

SAR 580 Experiment

Work on data derived from the Synthetic Aperture Radar Experiment (Annual Report No. 51) has so far been limited to the interpretation of optical products in X and C band[14]. Once digital information has been received for the six test areas selected from the entire strip and has been correlated with ground information, a final assessment of SAR as an all-weather sensor for natural resource surveys and agricultural research applications in Scotland will be made. In the meantime steps are being taken to digitise the optical film strips and relevant aerial photographs acquired during the mission. The report on the ground data collection programme, submitted to the European Space Agency, has already been published. 118, 119

Goodyear Airship Experiment

From June 3rd - 8th, 1982, the Goodyear Airship " Europa " was used to carry out a number of scientific aerial surveys over Highland lochs using remote sensing equipment. The expedition was organised by the Scientific Exploration Society and the British Chapter of the Explorers Club. Members of the Department together with a team from the University of Aberdeen and Robert Gordon's Institute of Technology carried out a number of experiments using a calibrated metric 70 mm camera and a video camera system, both from the airship and from two Cessna aircraft.

The main experiment was aimed at fulfilling an EARSEL Working Group 4 remit to study the value of microwave imagery at the air/water and land/water interfaces. In this case, the experiment was expanded to evaluate imagery from the Landsat, Seasat and Space Shuttle programmes. A combined air and sea operation was executed in the Beauly Firth between 1100 and 1400 hours BST on 7th June, 1982, under ideal tidal and meteorological conditions. The major achievement of this experiment was the successful testing of the Airship " Europa " as a stable, slow moving platform for collecting low level (from 500 to 1000 feet in particular) air truth information for the calibration and correlation of data from future space missions, in particular the next microwave experiment planned using the Shuttle Imaging Radar (SIR B). The airship was found to be particularly suitable for use in tandem with a slow moving boat for monitoring rapidly changing coastal hydrographic and sedimentological conditions.

Another experiment set up by the Highland River Purification Board investigated the dispersal of sewage from Inverness into the Beauly Firth. Eleven kilos of a red dye were released from the sewage outfall and aerial photographs and video films were taken at set intervals from the airship, enabling the dispersal of the dye to be followed on the flood and ebb tide. The results will be evaluated in conjunction with the hydrographic measurements and airborne imagery collected by the Institute, RGIT and Aberdeen University. 118

Developments and Applications of MAPIPS

Addition of a tri-axis locator to the B8S stereoplotter and acquisition of a Wild Aviotab plotting table with PRI-interface has enabled full utilization of the hybrid Macaulay automated photogrammetric and image processing system for output of classified data, in vector or raster form, for interpretation and mapping applications[15]. As an image processing system, the main advantage of MAPIPS is its ability to display and output classified Landsat data together with display of digitised ground information and air-photogrammetric plots in digital form. Both computer systems, the time-sharing Data General Eclipse and the CBM Pet microcomputer, play an integral part in the process. Input of Landsat data and classification procedures are performed via the Eclipse. Colour graphic output is achieved using the Tektronix 4027 terminal which is initially called by the Pet in order to store the required colour pattern sequence for the work in hand. In the presentation of classified data on the Tektronix for interpretation and correlation with other data, the most significant achievement has been through the development of a pattern definition facility[16]. The addition of the tri-axis locator to the stereoplotter has also enabled the development of two digitising work stations, a photogrammetric one using the B8S and a cartographic one using the Ferranti-Cetec System Four, both of which can be manned simultaneously. The rotary encoder on the system four, formerly linked to the B8S, can now be used on the Bendix digitising board for the manual adjustment of values in the third dimension (e.g. spot heights) or feature-coding digitised categories.

A recent improvement to the microcomputer operating system has been the option of relative files, which play a vital role in data editing. This facility enables the user to define the section of the file to be edited. Using the Aviotab, a plot is then made which will reveal faults in digitising, as for example mismatches at nodes or areas missed or duplicated. Co-ordinates of the relevant points may then be re-accessed and printed on the plot together with the file name. Output of the edited file can be achieved via the Pet high resolution graphics screen, the Tektronix 4027 or, for precision cartography, the Aviotab TA. 118, 119

In collaboration with the Departments of Soil Survey and Statistics the display of soil survey information on MAPIPS has been used to produce interpretative maps for DAFS and the NCB Opencast Executive. Survey information from the Keirsbeath Opencast Site produced by Dr J. H. Gauld was geocoded in grid form and single feature maps showing the distribution of subsoil and topsoil depths and topsoil texture produced.

119, 5703, 801

Airborne Thermographic Survey

Analyses of thermal imagery from the airborne survey of December, 1980, have been completed for selected areas of Aberdeen, using a specially assembled microcomputer system[17, 18, 19, 20, 21]. Following a request to evaluate the imagery for assessing roofing performance, further data were extracted from the original analogue recordings. Analysis showed that

although thermal data is of potential value for this purpose, only major contrasts between roofs were revealed on this occasion, mainly because the survey was carried out under sub-optimum conditions. A report with recommendations for future surveys has been submitted to the City Architect's Department[22]. 120

Instrumentation

Collaborative work with the Department of Spectrochemistry on the construction of a scanning field spectrometer for crop and vegetation studies has continued. This equipment will be necessary to provide correlation with Landsat spectral reflectances and those obtained from the airborne scanner also under development. A Rofin laboratory monochromator has been rehoused and the optics designed to give a nominal field of view of 1 m diameter at a height of 2 m. The instrument is attached to a portable frame and linked to an Apple II microcomputer incorporating an 8-bit digitising unit. Digitised spectra are stored on floppy disk and manipulations are carried out using software adapted from a specially written infrared spectral analysis package. Following further laboratory tests it is intended to begin a field programme in 1983. 118, 207

Nutrient Cycles in Forests

Analysis of samples and processing of data from the Sitka spruce *(Picea sitchensis* (Bong.) Carr.) nutrient cycling study continues to be a major preoccupation. This investigation is centred on six experiments designed to elucidate the relationship between growth and element cycling in closed-canopy forests. Trees and soil organic layers were sampled at the initiation of each experiment and again after five years, when samples were taken separately from replicated fertilized and unfertilized plots. During the intervening period samples of incident rainfall, and, in every plot, of throughfall, stemflow water and litterfall were collected fortnightly. All the water and tree samples have now been analysed, as have most of the litter-fall samples, but samples of the soil organic layers have still to be separated and analysed. To expedite this an automated method of separating the collected litter into needles and twigs is being developed. 115

Processing and publication of results from an earlier study of nutrient cycling in Corsican pine *(Pinus nigra* var. *maritima* (Ait.) Melv.) continues. Models of the flux and accumulation of nutrients emphasise the extent to which nutrient cycles, once fully charged, supply the needs of the tree. As a result, the demands made by the trees on reserves of nutrients in the soil is markedly less when the trees are large than when they are small (Fig. 2.2)[23]. Furthermore, large trees obtain greater amounts of nutrients from the atmosphere through the impingement and trapping of wind-borne salts on the tree surfaces, a process that may add significant amounts of nutrients to the soil[24]. The importance of these changes in nutrient input and cycling as trees age has been examined in relation to the use of fertilizers in forestry[25]. It is suggested that fertilizers are unlikely

to be of any benefit after canopy closure unless the nutrient cycles are disrupted, perhaps by a thinning or insect attack, or if immobilization of nitrogen in the humus reaches the stage at which supplies of this nutrient become limiting. It follows that the forest manager has greatest influence over the development of his crop during the years prior to canopy closure, when both fertilizers and weed killers can be used to significantly reduce the rotation length. These management implications are being further tested by the construction, largely by an NERC/CASE student, of a simulation model of the nitrogen control of growth in pine. Initial indications are that an effective predictive model can be developed. 115

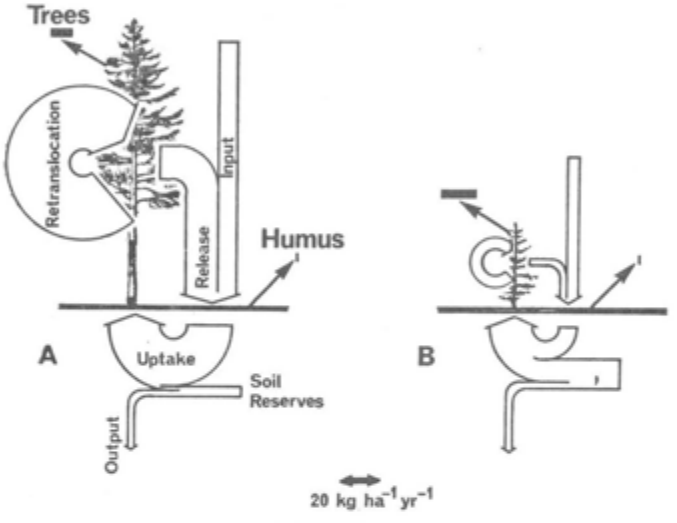


Figure 2.2
Patterns of cycling of potassium in (A) 11 m tall and (B) 2 m tall pine. Widths of arrows are proportional to the fluxes and lengths of solid bars are proportional to the rates of accumulation.

Recently attempts have been made to determine whether the ideas on nutrient cycling developed for evergreen pine also apply to broadleaved deciduous species. Models have been prepared of cycling by age for alder (*Alnus* spp)[26] and birch (*Betula* spp) based on information drawn from the literature. Interest in alder arose from its proposed use in short-rotation, high-yielding, energy biomass forests, whereas birch was considered important because of its reputation as a soil improver. For both species the pattern of nutrient cycling was found to be essentially the same as that for pine. Indeed, the demand by fast growing alder for soil potassium was maximum as early as age 2 years, but by age 4 had fallen to a fifth of this amount and was less than the likely rate of potassium input from the atmosphere. Similarly, the models for birch predict that, over a 45-year-rotation, the soil only supplies between 20 and 30 per cent of the tree's total nutrient requirements for growth, the shortfall being made up by continual recycling of this quantity through the tree-soil system. 115

Nutrition of Coniferous Trees

In many parts of the world fertilizers are regularly applied to coniferous forests[27]. It is clearly desirable to ensure both that nutrient deficiencies are properly diagnosed and that there is efficient use of applied fertilizer nutrients[28]. New experimental data, drawn from field and glasshouse experiments, have shown that the concentration of nitrogen in foliage of Corsican pine associated with maximum growth changes progressively with age, declining from a value of over 3 per cent nitrogen in young seedlings to 1.4 per cent prior to canopy closure, only to rise again to 2 per cent once the canopy is fully developed[29]. The reason for this pattern of change has not been established, but is thought to be a function of changes in the sink-source relations for nitrogen within the tree as it ages. 115, 117

In cooperation with the Forestry Commission, the Water Research Centre, Tayside Regional Council and the Institute's Department of Spectrochemistry, an experiment has been established at Angus forest, near Brechin, with the objectives of (1) investigating the effects of liquid sewage sludge on the development of a pole-stage stand of Scots pine *(Pinus sylvestris* L.) and (2) monitoring any possible harmful environmental effects of the application. The Forestry Commission is responsible for the establishment and maintenance of the experiment, the Water Research Centre is checking on possible contamination in neighbouring waterways and the Institute is monitoring changes in levels of nutrients and heavy metals in both trees and soil. In conjunction with the Department of Soil Survey, an intensive sampling of the soil and surface organic layers was carried out prior to treatment and these samples, together with samples of the sludge applied, are presently being analysed. Samples of foliage and further samples of soil will be taken at intervals throughout the duration of the experiment. 117

Forest Nursery Nutrition

As in previous years, the department continues to provide a nutrition advisory service to forest tree nurseries based on soil analysis carried out by the Department of Soil Fertility. In response to an increasing interest by nursery managers in the use of liquid fertilizers, particularly in dilute solution applied as a top-dressing, a series of experiments has been carried out in conjunction with the Forestry Commission to compare various possible fertilizer regimes based on liquids with more traditional regimes based on solid fertilizers. Preliminary results suggest that similar tree growth can be obtained with either form of fertilizer; the choice would then seem to rest on management criteria. 117

Studies on Acid Rain

Although not part of the original objectives of the nutrient cycling study in spruce, referred to earlier, an interest has developed during the course of the investigation in the interaction of trees with acid rain. This is facilitated by the geographical spread of the six experimental sites, ranging from the relatively unpolluted west coast (rainfall pH *ca.* 4·7) to the

more polluted east coast of Scotland (rainfall pH *ca.* 4·1). Although there seems little reason to suppose that the acidity presently found in rain will harm trees[30], there seems to be good evidence that rain-derived acidity can reach streams, a process that may be exacerbated by the presence of trees. The role of forest growth as a possible cause of soil and water acidification through the uptake and accumulation of excess cations, has been examined in some detail using results from both Macaulay studies and a range of Swedish investigations[31]. Despite the fact that the biologically generated acidity can be greater than that introduced in rainfall, it was concluded that because this transfer of hydrogen ions occurs without movement of an anion, the acidity will remain in the soil. Rain input, by contrast, is generally accompanied by the mobile sulphate anion, arrives in markedly episodic events and may be channelled through the soil profile. Because of these factors some of the hydrogen ions and accompanying anions may then reach streams. 115

This leaves unexplained the suggestion that trees facilitate the movement of pollution-derived acidity into waterways. Generally, throughfall collected beneath closed-canopy spruce is less acid than incident rainfall, and although stemflow is usually more acid, the quantities of hydrogen ions involved are small. Examination of the five years of data from each of the six spruce experiments, however, has revealed that, whereas at relatively unpolluted sites throughfall pH remains consistently greater than that of incident rain, at polluted sites the neutralization process appears to breakdown in mid-winter, leading to episodically high inputs of hydrogen to the soil at a time when this is already saturated and profile drainage is restricted[32]. Similar variations have been found beneath a range of other species on the polluted east coast, although ground vegetation, where present, is proving to have an important modifying influence[33]. These aspects are being investigated further. 115

Following suggestions by some German workers that aluminium mobilized in soil by pollution-derived acidity may be destroying tree roots, a glasshouse experiment has been established to determine the levels of aluminium and calcium at which such damage occurs. Preliminary evidence suggests that the critical levels are unlikely to be encountered in Scottish soils subjected to the rates of acid input presently being encountered. 117

Nitrogen Mineralization in Peat and Mor Humus

A study of particle size fractions, separated from peats by a wet sieving technique, has shown that these acid organic soils contain materials with wide ranges of nitrogen contents, carbon to nitrogen ratios and rates of carbon turnover (measured by carbon dioxide evolution during incubation). Nitrogen contents are generally higher in the smaller sized plant remains whereas rates of carbon turnover are highest in coarse fibres $>0{\cdot}5$ mm and diminish with decreasing particle size with an upturn in the fine fraction (0·005-0·05 mm)[34]. The pattern of variation of carbon turnover and nitro-

gen content with particle size is similar in peats from both blanket and cut-over raised bogs though the lower fertility of the latter is reflected by very low rates of carbon and nitrogen mineralization. 116

The pattern of release of mineral nitrogen from different size fractions during incubation suggests that the microbial biomass is unevenly distributed between the plant components and this hypothesis is now being tested in joint experiments with the Departments of Microbiology and Soil Organic Chemistry using ^{14}C labelling techniques. 116, 305, 512

In collaboration with the Department of Microbiology, samples of peat and forest humus have been used to test the effects of chloroform fumigation on the release of carbon, nitrogen and phosphorus from killed micro-organisms. Relationships between the size of the microbial biomass, once established, and the magnitude of the effects of fumigation could provide a means of estimating the nutrient content of the microbial biomass, which has a relatively rapid turnover in soil and is a potential source of plant nutrients. Biomass measurements on a range of acid organic soils, based on substrate amendment methods, have been found to correlate positively with the amounts of nitrogen transformed to ammonium during a water-logged incubation at 30°C. 116, 503

In the joint study with the Department of Microbiology on the effects of water-table level on the bacterial populations and nitrogen availability in peat, work has concentrated mainly on the consequences of maintaining samples in an anaerobic environment during transfer from the field to the laboratory. 116, 503

In an attempt to obtain a measure of the amount of mineral nitrogen produced in litter and humus under field conditions, samples of the forest floor beneath Sitka spruce at Fetteresso forest were incubated in both open and closed pots under the trees. The mineral nitrogen that accumulated in closed pots over 12 months was equivalent to 52 and 17 kg N ha^{-1} in litter and humus, respectively. Application of NPK fertilizer, which raised the pH of the forest floor materials and stimulated nitrification, resulted in an accelerated leaching of mineral nitrogen in the open pots[35]. 115, 116

The *in situ* incubation technique has been extended and applied to the study of nutrient release from litter and humus of different tree and plant species at Glen Tanar, near Aboyne. These include young and old Scots pine, larch, Sitka spruce, birch and heather. 115, 116, 512

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3. SPECTROCHEMISTRY

A. M. URE

The work of the Department of Spectrochemistry again encompasses the four main themes of previous years. These are 1) the investigation of the distribution of trace elements in soils, soil profiles and plant materials. 2) the examination of the structure, composition and forms of soil constituents. 3) the provision of an analytical service for trace and major elements to the Institute and the North of Scotland College of Agriculture and 4) the development of spectrochemical methods for the implementation of these programmes.

Trace Elements in Soil, Plants and Biological Materials

The routine work of analysing soils and plants from field experiments, conducted in collaboration with the Department of Soil Fertility, has continued to occupy much of the Department's time. It is only after many years of patient work, carried out despite competing short-term claims on resources and restriction of support staff, that the results, vital to the assessment of the factors affecting trace element availability to plants, can be evaluated. Fig. 3.1 illustrates, from preliminary field experiment findings, the crucial role, for example, of soil drainage conditions on trace element availability. It is also indicative of the analytical effort required to provide practical information of direct value to agricultural production.

Much effort has again been devoted to the problems of heavy metals and other elements introduced to soils and plants by the use of sewage sludges and other effluents on agricultural soils. Work has continued on the analysis of samples from ADAS long-term sewage sludge experiments and, in collaboration with the Department of Peat and Forest Soils, an experiment to assess the effect of disposing sewage sludge on forest land has also been initiated. This complements similar work on agricultural land in the Department of Spectrochemistry.

Certificate analysis of 3 soils and 3 sludges in collaboration with the Community Bureau of Reference of the EEC has now been completed and, after evaluation of the results, these materials should be available as Certified Reference Materials, probably in 1983. These materials will be invaluable for validating analytical methods especially if legislative control of sludge application is introduced.

The comprehensive compilation, from the world literature, of the elemental contents of soils (Annual Report 51) has now been published,

and recent advances in analytical capability have been reviewed[2]. The analytical problems posed by the biosignificant trace elements in agriculture and the role of atomic spectroscopy in solving them have been reviewed[3, 4].

Soils and Soil Parent Materials

The determination of trace elements in selected soil profiles sampled by the Department of Soil Survey has continued. Extractable molybdenum determinations in upper horizons of soil profiles from Sheets 40 and parts of 41 and 32 (Kinross and Elie) and Sheets 43, 44 (Isle of Mull) have been completed and those from Sheet 85 (Rothes) are in progress. Work on the determination of extractable trace elements in soils from the area covered by Sheet 75 (Tomintoul) is nearing completion. 101, 201

A report on trace elements in fifty representative profiles from fifteen different Associations from the Kinross and Elie area (Sheet 40 and parts of 41 and 33) has been prepared for inclusion in the Soil Survey Memoir. The geological nature of the rocks from which the soil parent materials are derived vary greatly in this area, partly because they are comprised of basic igneous rocks, Carboniferous and Old Red Sandstone sediments and their intruded lavas. The action of ice has, in addition, contributed to their diversity, with the production of some mixed tills along the edges of these formations, and these tills have been further modified by the action of fluvioglacial melt-waters. These differences in the geological nature of the soil parent materials are reflected in, for example, the differences in the trace element contents of the Darleith, Sourhope, Eckford and Fraserburgh Association soils. Weathering and water-sorting on the glacial deposits to produce parent materials of a largely sandy, silty or clayey texture has also had an influence on trace element distribution. Soils of a predominantly sandy nature such as those of the Eckford, Darvel, Fraserburgh and Links Association are inherently low in total cobalt and likely to give rise to cobalt deficiency problems in ruminant animals. Although in some cases only a small number of profiles have been examined, it can be concluded that freely drained soils of some other Associations, including the Giffnock, Hindsward, Kippen, Mountboy, Sourhope and Alluvium, in addition to those mentioned above, may also be cobalt deficient. Problems of copper deficiency affecting cereal growth might be anticipated on some soils of the Eckford, Fraserburgh, Kippen and Panbride Associations. The results suggest that the possibility of molybdenum-induced copper deficiency in animals cannot be excluded on the soils of some other Associations, such as Dreghorn, Eckford and Sourhope. 101, 201

A study of the variability in the total contents of eight trace elements in the C-horizon samples of 59 soil profiles of the Ettrick Association has now been published[5]. 101, 201, 703

A paper reporting the total lead levels in nearly 4000 soil samples from about 900 profiles taken throughout Scotland has been prepared for publication. Because the frequency distribution of concentration levels is approximately log-normal, a statistical transformation of the data

provided a more satisfactory means of describing the distribution. The total lead concentrations in the bulk of Scottish soils lie within the range 2·5 to 85 mg/kg with an average value of 14 mg/kg. The lead concentration in organic soils is generally higher and more variable than that in mineral soils. As reported in earlier findings, the most prominant feature of the vertical distribution of total lead is the enrichment of surface horizons. An inverse relationship between total lead concentration and the sand content of the soils was also found. 101, 201

Soil Status and Plant Uptake

The department has collaborated, as in previous years, with the Department of Soil Fertility in the analysis of soils and plants from field experiments. This commitment continues to suffer from the rapid turnover of junior staff with a consequent large training component in the programme of work. This is particularly important in plant analysis by the concentration procedure where approximately 25% of the analyses were training samples. A modest improvement in staff complement at the junior level in this area would provide handsome dividends in more rapidly evaluating field experiment results.

A series of papers discussing the results of four long-term field experiments to study the effects of major element fertilizers, particularly nitrogen, on the uptake of trace elements by herbage is in preparation.

A preliminary assessment of the results obtained so far for the Co, Cu and Mo contents of mixed herbage and the amounts extracted from the related soils by acetic acid, EDTA or ammonium acetate has confirmed earlier findings. i.e. that plant trace element uptake is enhanced in poorly drained soils. The results also show that the relation between plant and soil Co contents are strongly influenced by drainage status, while those for Cu and Mo are not (see Fig. 3.1). For instance, a level of 1 μg Co g^{-1} soil extracted by 0·43 M acetic acid is likely to be associated with a mixed herbage Co content of $<0{\cdot}1$ μg g^{-1} dry matter (DM) if the soil is freely drained but of $0{\cdot}2$ μg g^{-1} DM if the soil is poorly drained. These findings are of considerable significance for advisory diagnostic purposes. 201, 202

Results from numerous field experiments carried out by the Dept. of Soil Fertility were presented at a British Society for Animal Production/ British Veterinary Association trace element symposium to illustrate effects of soil drainage, liming, fertilizers and trace-element soil treatment on crop composition and yields[6]. Among the effects, attention was drawn to the persistence of enhanced plant molybdenum uptake over a 20 year period following its application to the soil. 201, 202, 609

Laboratory and pot experiments are being carried out in collaboration with the Department of Soil Organic Chemistry to study the effects of adding increasing amounts of peat, of low copper content, to two soils heavily contaminated with copper as a result of long-term disposal of distillery waste. 201, 307

Analysis of soils from two long-term sewage sludge experiments at ADAS Experimental Horticulture Stations has continued with work on

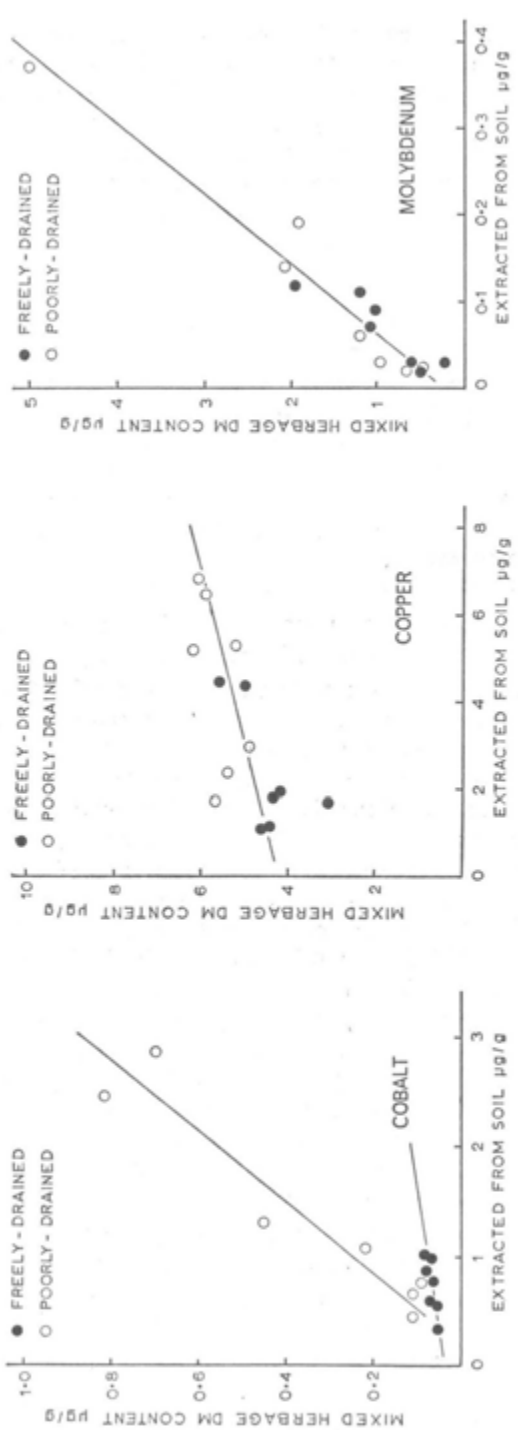

Figure 3.1

Trace element research: relations between plant and soil contents. The diagrams illustrate relations between the cobalt, copper and molybdenum contents of mixed herbage from temporary grass/clover leys and the amounts of these elements extracted from the related soils by the reagents routinely used for providing advice to farmers (acetic acid for Co, EDTA for Cu and ammonium acetate for Mo). Each point is the average of 9 plant and 9 soil samples, obtained by sampling 3 times each year for 3 successive years (1969-1971) at field sites in north-east Scotland on a wide range of soil parent materials. The diagrams show that plant contents of all 3 elements are higher on the poorly drained soils, but that only for cobalt is there a significant difference in soil-plant relations between the freely- and poorly-drained soils.

the determination of extractable trace elements contents of soils sampled in 1981. At the invitation of the Institute for Scientific Information, Philadelphia, USA, a brief commentary on the background to some of the early work on the trace element composition of sewage sludges carried out in the department has been published as a Citation Classic[7] in Current Contents.

Work reporting the persistence of metals in available form in sewage sludge treated soils, following a presentation made at the European Society for Nuclear Methods In Agriculture meeting held in Aberdeen in September 1981, has been published[8].

A chapter entitled, "Uptake, distribution and effects on plants", to appear in a book, "Metalle in der Umwelt" edited by E. Merian, is to be published by Verlag Chemie in German[9]. 201, 202

A long-term investigation, in collaboration with the Forestry Commission, the Department of Peat and Forest Soils and the Water Research Centre, has been started to evaluate the potential of sewage sludge as a fertilizer for forest trees and the environmental consequences. Samples of surface soils and soil profiles taken at Montreathmont Forest and of the Brechin sludge used as fertilizer have been prepared for analysis. 115, 201

Analysis of samples of peat and of foliage from conifers growing on Forestry Commission experimental sites where copper deficiency is suspected has continued. 117, 201, 202

In collaboration with the Department of Microbiology an investigation began into the effects of fumigation and/or irradiation on the levels of extractable metals in soils. Such treatments may release extractable trace elements from the killed biomass. Preliminary findings suggest that the effects on acetic acid- and EDTA-extractable trace elements in an Insch Association soil are generally small. Much larger effects were found on the amounts of trace elements extractable by neutral molar ammonium acetate, particularly for manganese. Further studies are in progress. 201, 512

A paper reporting the use of 2-ketogluconic acid, (Annual Report 51) a naturally occurring acid produced by soil bacteria in the rhizosphere, as a soil extractant for trace elements has now been published[10]. 201, 202, 502

Miscellaneous materials analysed during the year include samples of sewage sludge from Grampian Water Services, zeolites from Robert Gordons Institute of Technology, plastics used for making feeding troughs from the Rowett Research Institute, bark from the Department of Soil Organic Chemistry and soils from Dr K. Jackson, City of Sheffield Polytechnic.

Spectrochemical Methods of Analysis

Spectrochemical[11] and other techniques[12] for the analysis of trace elements have been reviewed and atomic absorption and flame emission methods for soil analysis have been surveyed and evaluated[13].

Arc Emission

No changes have been made to arc emission methods of analysis. A Russian report that vanadium quinolate could be readily vaporised into a carbon-arc led to a brief investigation of the behaviour in the cathode-layer arc of 8-hydroxyquinoline-tannic acid-thionalide precipitates, in their unashed state. It was found that the arc sensitivities for several elements, e.g. Co, Mo, V and Zn, were roughly comparable in the unashed precipitates and in alumina, (the matrix formed when the precipitates are ignited in the usual procedure). However, the much greater mass of the unashed precipitates decreased the weight-concentration factor obtainable by ignition and resulted in an overall reduction of analytical sensitivity. In addition, the finely divided, light powder state of the dried precipitates made them very inconvenient to use. It was concluded that there were no advantages to be gained by not igniting the precipitates. 205

Flame Emission and Atomic Absorption Spectrometry

Methods of Sample Preparation. Zinc and cadmium are two of the heavy metals which require monitoring when sewage sludges are disposed of on agricultural land. These two elements cannot be satisfactorily determined by cathode layer direct-current arc analysis, because of poor sensitivity. This fact, and the department's involvement in the certification analysis of 3 soils and 3 sewage sludges, carried out under the auspices of the Community Bureau of Reference of the EEC, have necessitated recourse to the use of digestion procedures for preparing samples for analysis by atomic absorption spectrometry. The evaluation of such procedures is especially desirable since most agricultural laboratories have access only to solution-sample spectrochemical techniques. Studies have therefore been made of digestion with HCl, HNO_3 and aqua regia in open and covered vessels. Aqua regia digestions were also performed in a teflon-lined bomb and under reflux on an electrothermal heater and the results compared.

The last digestion procedure, prescribed for the certification analysis, has proved the most suitable and has been adopted by this department for future assessment of metal contaminant levels in soils and sludges. The aqua regia reflux digestion procedure is briefly as follows:

> To a 1-3g sample of finely ground dry material (soil or sludge), moistened with 2-3 ml distilled water in a 100 ml flask, 7·5 ml of redistilled 6M HCl followed by 2·5 ml redistilled conc. nitric acid per gram of dry sample are added, the flask covered and left overnight at room temperature. The contents are then boiled gently under reflux for 2 hours, allowed to cool and the condenser rinsed into the flask. The contents are filtered through a Whatman 542 filter paper and, together with rinsings, made up to 100 ml with 2M nitric acid for analysis.

Such digestion procedures do not measure true total trace element soil contents, as silica-bound elemental constituents are not rendered soluble, but, for pollution assessment, this fraction is usually insignificant. The

aqua regia procedure adopted is reproducible for most elements (ca. ± 10%), and extracts at least 80% of the total contents of Cr, Cu, Pb, Ni and Zn from sewage sludges. Analyses of the Canadian Standard Reference soils showed that some 80% of the total Zn and Cd were also extracted from uncontaminated soils.

The mean percentages of the total contents extracted by aqua regia from the four Canadian Reference soils and six typical uncontaminated Scottish topsoils from a wide range of geological parent materials were: Al 36, Cr 63, Cu 85, Fe 87, Pb 63, Mn 70 and Ni 50. A paper reporting this work, which was presented at the First Biennial National Atomic Spectroscopy Symposium held in Sheffield, has been submitted for publication[14]. 201, 206

The suitability of Kjeldahl digests of plant material using mercury or selenium catalysts, prepared primarily for nitrogen and phosphate determination, for the determination of the major cations Ca, Na, K, and Mg by atomic absorption spectrometry, has been assessed in collaboration with the Department of Soil Fertility. Both catalysts were suitable for cation determination but the possible health hazards associated with the use of mercury have persuaded us that the procedure using selenium catalyst is preferable despite the contamination problems the latter may present. This, it is hoped, will be minimised by making use of laboratory segregation and the large sample dilution made possible by the high sensitivity of the inductively-coupled plasma emission spectrometer about to be commissioned for this purpose. 206, 5206

An automated combustion apparatus (Trace-O-Mat, VAE, Paar Scientific Ltd.) has just been installed, which combines combustion in a stream of oxygen, liquid nitrogen trapping of volatile components, and refluxing with nitric acid, to provide a method for mineralising organic materials wthout loss of volatile elements such as selenium. This equipment is now being evaluated. 205, 206

A Cell-Roller machine, more commonly used for oxygenating microbiological cultures, is being evaluated as a possible alternative to the traditional end-over-end shaking machine used for extracting trace elements from soils. Some of its potential advantages are:- it requires a smaller floor area, it uses less electrical power, samples can be removed from the machine without interrupting the rolling of others and the absence of hazardous moving parts. 205, 206

Instrumentation. The interfacing of the three-channel atomic absorption spectrometer for the determination of Ca and Mg in soil extracts with an Apple II microcomputer has now been completed, (Annual Report 51). Problems associated with the vulnerability to electrical interference of the simple interfacing system used initially have been solved by the use of a serial RS232 interface and an improved key-board. 206

The method for determining ten major and minor elements in small rock and soil samples (ca. 50 mg) using a lithium metaborate fusion/nitric

acid dissolution technique has now been published[15]. An auto-sampling system with aerosol sample injection (IL FASTAC 254) has been installed for use with IL 555 graphite furnace atomic absorption accessory although the system can also be used for flame methods. This will improve the precision and speed of furnace atomic absorption spectrometric analysis. 206

Developments in atom-trapping atomic absorption spectrometry, which have been discussed in published papers, include the use of metallic trapping tubes[16], and the determination of Se[17] with a detection limit of 0·034 mg l^{-1} which compares favourably with the 1 mg l^{-1} detection limit obtainable by conventional flame methods. The latter paper also demonstrates the advantages of aluminium oxide-coated collector tubes in minimising interference effects. Other work in this field, accepted for publication[18], demonstrates that the high sensitivity of the technique makes it possible to determine Cd and Pb directly, for example, in acetic acid extracts and aqua regia digests of soils at μg l^{-1} concentrations. This research carried out by Mr Lau, Chau Ming is being submitted for the degree of Ph.D. at Aberdeen University this year, and was described by him in the prize-winning paper[19] delivered at the Research Topics meeting of the Analytical Division of the Royal Society of Chemistry held in York. The value of this technique is that it allows direct practical analysis of solutions for a range of elements by a simple, specific and reliable flame technique with a sensitivity which approaches that of graphite furnace atomic absorption. Appreciable (10-40x) gains in sensitivity have been demonstrated for some 12 elements, Ag, As, Au, Ni, Cd, Cu, Mn, Pb, Sb, Se, Tl and Zn.

Analyses. The number of routine determinations of major cations and of Al, Cd, Ni, Pb and Zn increased this year while that of Co, Cu and Mn was unchanged. Overall some 100,000 elemental analyses were carried out by established flame spectrometric procedures — an increase of some 10% over the previous year.

Some 2000 analyses have been carried out by atomic absorption spectrometry for which specialised sample treatment or non-routine analytical techniques were required. Analytical assistance has been given to other establishments including the Scottish Crops Research Institute (Ca) and the Centre for the Study of Metabolism of Trace Elements, Aberdeen University. 206, 5206

Microwave Plasma Emission

A small study of ^{13}C: ^{12}C isotope ratios, using the microwave plasma emission equipment previously constructed for measuring ^{15}N: ^{14}N ratios, has confirmed that the Hilger and Watts D331 spectrometer has inadequate throughput of light and insufficient resolution. Further development of equipment for determining ^{13}C: ^{12}C ratios has been postponed until a better spectrometer (an Optica CF4) has been equipped with stepper motor control for wavelength scanning. 205

Radiofrequency Plasma Emission

A clean room has been established for the inductively-coupled plasma (ICP) emission spectrometer using an air filtration/room pressurization system to provide environmental control and also to minimize contamination of samples from air particulates. The computer and spectrometer have been interfaced and, currently, computer control of the operating parameters and sample introduction system are being introduced. Further studies on the fluid dynamics of nebulizer operation have been undertaken and these are now being extended to include the associated spray chamber and plasma torch injector. It is intended shortly to make use of this equipment for routine determination of major cations in (initially) plant digests. Agricultural applications of ICP have been reviewed[20].

Laser Spectroscopy

Measurements using the laser remote sensing system, constructed from equipment supplied by the Royal Society, the Science Research Council and the Agricultural Research Council, have continued and further software has been developed to allow the results to be analysed on the Institute's Data General Eclipse computer. Mr P. Wilson, formerly an ARC postgraduate student and now of the department of Soil Fertility, is currently preparing his Ph.D. thesis on this work for submission to the University of Aberdeen. Laser remote sensing of atmospheric pollutants has been the subject of a review paper[21].

Spark Source Mass Spectrometry (SSMS)

Work aimed at establishing Relative Sensitivity Coefficients for 50-60 elements in biological matrices has continued with the completion of the analysis of six series of synthetic powder standards based on a simulated liver base. These data are now being evaluated and a similar series of synthetic soil standards is being analysed for comparison purposes.

Comprehensive analysis of a biological material such as liver will require a combination of analysis of the sample ash and analysis of a chemical preconcentrate for those elements too low in concentration to be determined directly in the ash or for elements subject to interference from major constituents. Both aspects, preparation by dry-ashing and pre-concentration procedures, have been studied and reported on at two International Conferences[22, 23]. The performance of various ashing aids, Al_2O_3, $Al(NO_3)_3$ and cellulose powder, for the dry-ashing of bovine liver were investigated and Al_2O_3 found to be the most suitable. The method hitherto adopted for preparing pure Al_2O_3 from pure aluminium ingot (99·999%) by dissolving in HCl, precipitating as hydroxide with pure aqueous ammonia and igniting the precipitate gave a product of insufficient purity for ultratrace analysis. In addition, despite careful washing, chloride remained strongly bound to the Al_2O_3. The presence of chloride not only increases the possibility of losses of elements forming volatile chlorides during ashing, but causes spectral interference, especially on the internal standard indium line, in the presence of potassium and calcium as major

components of the sample. A superior product, free of chloride, could be prepared by dissolving pure amalgamated aluminium wire in nitric acid, evaporating the solution to dryness and igniting. The inadequate purity of the available aluminium powder used as the conductor in the formation of electrodes for SSMS constitutes one of the principal restrictions to the detection limits obtainable for some elements. Preliminary attempts to prepare a pure powder from Al wire or ingot have been unsuccessful, largely because the manufacturers' ostensible 99·999% purity were considerably optimistic. This problem will require further consideration.

Freeze-drying equipment has been installed and used to prepare bulk samples of dried bovine blood (fresh blood supplied by Rowett Research Institute) and dried bovine liver to provide local reference samples. To avoid contamination, in the milling of samples, by elements such as Fe and Cr from stainless steel knife blades, and Cu, Sn and Zn from bronze bearing materials, a Waring Blendor has been modified for this purpose by replacing the stainless steel knives by titanium knives, and the bronze bearing by a graphite one of spectrographic purity (Ringsdorf RW IV). Titanium knives were also used to dissect the bovine liver sample. A reduction in chromium contamination has been achieved by these methods[22].

Much of this work has been carried out in the department by Dr. C. A. Shand, supported by the Scottish Hospitals' Research Endowment Trust, in collaboration with Dr P. J. Aggett of The Centre for Study of Metabolism of Trace Elements, Aberdeen University, with a view to establishing analytical methods for the comprehensive analysis of biological materials of animal and human origin.

In a collaborative study with Dr A. Gelman of the North of Scotland College of Agriculture, samples of duodenal digesta from sheep, whose diet had been spiked with ruthenium to act as an inert marker element, were analysed by SSMS, by GFAAS* and by instrumental NAA** (with the collaboration of Dr J. E. Whitley of the Universities Research and Reactor Centre, East Kilbride). It was found possible to determine ruthenium by SSMS analysis of the unashed sample, without interference from the complex and largely organic matrix, by making use of the $^{99}Ru^{2+}$ and $^{101}Ru^{2+}$ ion lines. This approach was adopted because of the expected volatility of ruthenium oxides or halides. Subsequent experiments demonstrated that, probably as a result of the high potassium content (and the formation of thermally stable K_2RuO_4), these precautions were unnecessary. 205, 206

Preconcentration of groups of elements by cementation on aluminium powder (Annual Report 51) for SSMS analysis has been further studied by Mr Fu Bin, visiting research worker from Beijing (Peking) China. Quantitative recovery from hydrochloric acid solutions has been achieved at the optimum conditions, viz pH 3, a temperature of 70° C and solution flow rates of not greater than 100 ml/hour, for the elements Ag, Au, Bi, Cu, Pb, Pt, Rh and Ru. Similar recoveries were obtained from 1% acetic acid solution under the same operating conditions. Interference effects from

* Graphite Furnace Atomic Absorption Spectrometry.

**Neutron Activation Analysis.

excesses of cementable elements such as Cu and Pb were small but the presence of Fe at concentrations exceeding 10 ppm interfered with the collection of 2-5 ppm of the analyte. Masking of Fe by approximately 1300 mg l^{-1} ammonium fluoride prevented interference by Fe in concentrations up to 1000 mg l^{-1}. Other elements, still under study, showing substantial recovery under certain conditions, especially of oxidation state, include As, Fe, Sb, Se, Sn and Tl. For Cr, recoveries so far are low and for Co and Ni near zero. The technique is being applied to waters, and soil extracts and sample preparation methods are being developed for biological and other materials. A discussion of the possibility of using cementation on aluminium metal for the removal of copper from copper-rich effluents before disposal on agricultural land has now been published[24]. A review of the application of SSMS to geological materials and natural waters (Annual Report 51) has been published[25]. 201, 205, 206

Developments in instrumentation have received considerable attention this year. One turbomolecular pump has been fitted to the second mass spectrometer and two others are being fitted, to assess whether, liquid nitrogen trapping can be dispensed with. It has been argued that multi-element electrical detection is an essential requirement for the future development of SSMS[26]. A further MS7, acquired for spare parts, has provided an engineering mock-up for the development of new detection systems and also an electron-bombardment source unit which may be useful for isotope ratio measurements and stable isotope tracer studies.

A microprocessor controller and data-processing unit has now been fitted to the scanning microdensitometer and is in routine use. Instructions for measuring spectral line and background densities on the photographic plate are made by punched paper tape or under keyboard control. Data output is presented by Teletype on punched paper tape or in printed form. The latter is used at present for computation of element concentrations using programmable calculators but it is intended to use the paper tape for computation by means of the Institute's main frame computer.

Samples analysed this year include soils, sewage sludges, minerals, algae, rice and wheat flour, liver, sheep digesta, and smelter dusts. 201, 202, 205

Molecular Fluorescence Spectrometry

A new scanning fluorimeter (Baird RC 2000) is being installed to replace the obsolete Beckman instrument for the determination of selenium. The development of an oxidative acid digestion procedure which uses a potassium permanganate rather than a perchloric acid oxidation stage has largely been completed. This should be suitable for both soil and plant analysis and a description of the method with comparisons with other sample preparative methods is in preparation. 206

Molecular Spectrometry of Soil Components

The considerable contribution that J. D. Russell has made over the years to soil science and to the work of the department has been recognised

with the award of the degree of D.Sc. by the University of Edinburgh for a Thesis on "The Application of absorption spectroscopy, particularly infrared, to the study of clay minerals, soil organic matter, soil additives and related compounds."

Optical Absorption Spectrometry. Imogolite is a hydroxyaluminium silicate with a unique tubular form whose atomic structure (Fig. 3.2) and method of synthesis were discovered at the Institute. Although first found

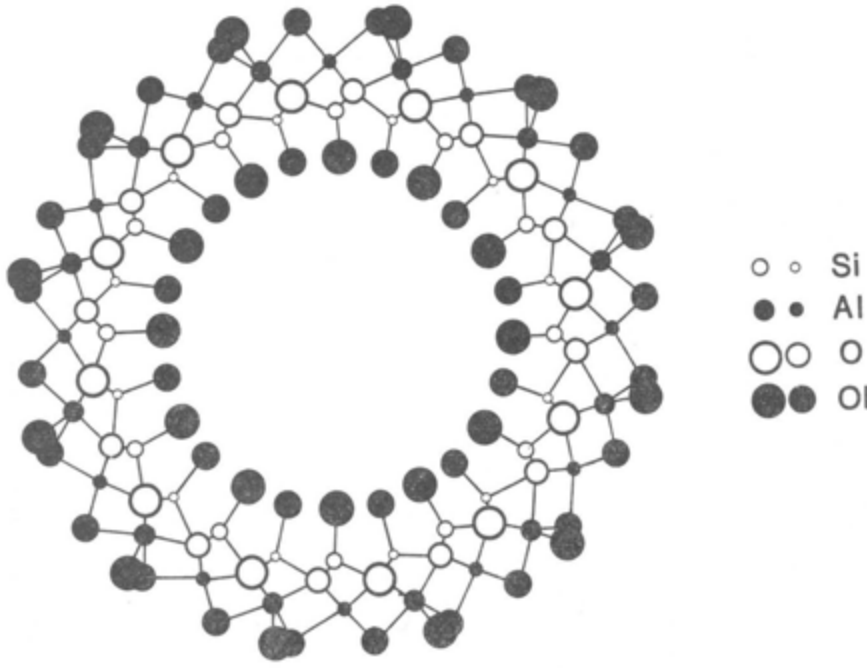

Figure 3.2
A cross-section of the tubular structure of imogolite shows five successive concentric cylinders of ions, in the sequence from the outside, hydroxyl, aluminium, oxygen, silicon, hydroxyl.

in volcanic ash soils, this mineral is now known to be a common constituent of podzols and podzolised soils, where it is associated with proto-imogolite allophanes of similar atomic structure, but lacking the tubular morphology. The significance of the occurrence of imogolite and proto-imogolite allophane in podzol B horizons is that its formation there is incompatible with conventional views of the mechanism of podzolisation, which invoke aluminium and iron fulvates as the mobile phase, but is consistent with the view that aluminium and iron migrate as hydroxysilicate complexes. A review of the arguments in favour of this mechanism has been accepted for publication[27].

Separate migration of organic matter in colloidal form in podzols developed on coarse parent materials, after the development of an A_2 horizon and surface organic horizons, is indicated by the distribution of humic and fulvic acids, and of organic complexes of aluminium and iron, in podzol B horizons[28].

A study of the chemical and colloidal stability of hydroxyaluminium silicate sols shows that they have the properties necessary to transport aluminium in podzols, and that they can also play a role in transporting iron in mixed systems[29].

Visits to Japan, Australia, New Zealand and Canada have confirmed that these mechanisms are generally applicable to podzols formed on freely drained coarse parent materials in a wide range of climates. Similar mechanisms, although with minimum translocation, appear to operate in the formation of weathered B horizons in acidic fine-textured soils in New Zealand and Canada: these are analogues of the Brown Forest Soils of Scotland. However, the water-logged humus podzols with cemented Bh horizons, characteristic of the coastal regions of sub-tropical Australia, do not incorporate allophane or imogolite, and clearly have different mechanisms of formation. A satisfactory characterization of podzols and podzolised soils therefore requires separate evaluation of the amorphous inorganic and organic forms of aluminium and iron, and a survey of standard techniques[30] has indicated that this can be achieved by extracting both inorganic and organic complexes with 0·2M oxalate buffer of pH 3 over 4h, and organic complexes with either 0·1M pyrophosphate, or 0·05M EDTA, pH 9. 207, 208, 201, 304, 801, 101, 105

A review of recent advances in analytical infrared spectroscopy has been published[31]. A translation of the standard advanced French text on soil properties and soil constituents[32] has been undertaken to provide easier access to French soil research, which has followed a distinctive line of development with many differences in emphasis and outlook from the Anglo-American tradition. 207, 208

In previous investigations of the interactions of anhydrous NH_3 gas — one of the most concentrated forms of nitrogenous fertilizers — and clay minerals such as montmorillonite or saponite (Annual Report No. 36) and vermiculite (Annual Report No. 42), infrared spectroscopy indicated that one of the major products of such interactions was exchangeable NH_4 ions. It was subsequently shown (Annual Report No. 48) that, in vermiculite, these ions constituted a particularly valuable source of fertilizer nitrogen whose rate of release for possible uptake by plants could be controlled by using particular size fractions of the ammonia-treated vermiculite, conveniently referred to as ATV. In collaboration with The Department of Soil Fertility it has now been shown that the vermiculite containing this form of NH_4 is at least as effective as conventional ammonium salt fertilizers in pot trials on a variety of crops. Marked fertilizer efficiency has been demonstrated for 0·25-0·5 mm ATV flakes with potatoes while a larger flake size (2·8-4·0 mm) showed a potentially useful

lower but more constant seasonal supply of nitrogen to ryegrass. A paper on this topic has been accepted for publication[33]. 207, 603

As a result of continuing collaborative studies with the Department of Soil Organic Chemistry, two lines of research have been brought to publication. In the first, earlier work on the characterization of a fungal melanin by infrared spectroscopy (Annual Report No. 49) had suggested that this black, chemically resistant pigment might accumulate in soil in the insoluble humin fractions of soil organic matter. In an extension of this work[34], infrared spectroscopy and chemical analysis have shown that soil humin was similar to soil humic acid, and resembled the melanin-like pigments from certain soil fungi, e.g. *Coniothirium minitans* and *Rhizoctonia solani*, but differed from that from *Aspergillus niger*. In the second, infrared spectroscopy, having been successfully used to evaluate the progress of methylation of extracted soil polysaccharide (Annual Report No. 48), has proved equally useful in following the repeated direct methylation of whole soil, a new technique designed to account for a higher proportion of the total soil sugars than that obtained by pre-extraction of the soil polysaccharide. It has been shown that successive products from the direct methylation technique, while retaining a relatively constant carbohydrate content, become depleted in peptides or protein and enriched in wax-like components[35]. 108, 208, 301, 395, 515

Collaborative research in conjunction with the Department of Mineral Soils has continued along several lines. Following on the recognition of Macaulayite as a new mineral incorporating both hematite and layer silicate structures (Annual Report No. 51), it has been established that a previously known iron oxide incorporating silica, so-called mellanosiderite, is in fact a siliceous ferrihydrite and unrelated to Macaulayite[36]. 104, 207

In addition to collaboration within the Institute, the section has, over the years, been involved with research projects initiated at other centres. One such recent venture has involved the Institute of Geological Sciences and the Department of Minerals Soils in a study of the mineral leadhillite, $Pb_4SO_4(CO_3)_2(OH)_2$. Authentic IR and XRD data have been submitted for publication in a paper which illustrates a previously unsuspected occurrence of isomorphous substitution of the anions in the leadhillite structure[37]. 104, 207

Instrumentation and Data Processing. The use of microcomputers as an aid in analysis has increased with systems in use in the infrared[38, 39] and atomic absorption laboratories. In the infrared laboratory a microcomputer has been employed for data logging from both the dispersive and Fourier spectrometers and software has been developed to permit extensive manipulation and analysis of this data. A direct line between this microcomputer and the Institute's mainframe computer has been established. This will enable data to be more efficiently stored and more complex data analysis performed.

In collaboration with the Remote Sensing Unit, a microcomputer-based system has been developed and successfully employed for the analysis of

airborne-recorded thermographic data of Aberdeen City and surrounding agricultural land[40]. A part of this work was commissioned by Aberdeen City Architect's Department and a report published[41]. A small, rapid-scanning spectrometer for the UV-visible region has been interfaced to the microcomputer unit and will be employed for monitoring soil and crop reflectance spectra for correlation with similar airborne — and satellite — recorded data. The processing of thermographic data by microcomputer has been discussed[42] and the principle and applications of aerial thermography described[43]. Microcomputer processing of remotely sensed data has also been considered[44]. Photoacoustic spectroscopy has recently been comprehensively reviewed[45]. 207

Mössbauer Spectroscopy. Two Fe Mössbauer studies of plant materials, (soya bean, pea and duckweed) have now been published[46, 47] and this subject has been reviewed[48]. The characterization of iron (II) and iron (III) species in the clay minerals montmorillonite and hectorite by Mössbauer spectroscopy has been discussed[49].

Electron Paramagnetic Resonance (EPR) Spectroscopy. In collaboration with the Department of Soil Organic Chemistry, *in vivo* studies on the uptake of vanadyl ion by wheat plants have now been completed. The sequence of events was found to be similar to that for copper (II) (Annual Report 49), except that copper (II) was not concentrated in the vacuole as was the vanadyl ion. The results have now been published[50]. The use of EPR spectroscopy, as a tool in the investigation of trace element uptake by plants, has been discussed[51].

Work has continued on low molecular weight model copper (II) complexes because of interest in the involvement of such species in biological systems and in their interactions with clay minerals. Experimental work on the copper (II)-diglycine system has been completed and the conclusions are being prepared for publication. It has now been shown that nine copper (II)-diglycine complexes can exist over a range of pH values, and, in many cases, hyperfine and superhyperfine coupling have given information on the coordination of the peptide around the central metal ion. The presence of cis-trans isomerism in a bis-complex has been demonstrated. Results were sometimes in conflict with structures postulated by other workers using electrochemical techniques.

Computer simulation methods have had to be used in the above work and this necessitated the development of a more sophisticated program for the solid state frozen solution simulations than was previously available. A program was developed for $S = 1/2$ systems, which incorporated three independent g and A tensors to cope with low symmetry situations. An axially symmetric contribution giving superhyperfine structure for up to four equatorial nitrogen ligands, with cis and trans configurations for two nitrogens was also included.

Studies on the adsorption of copper (II) complexes on imogolite and montmorillonite have been completed and the results submitted for publication[52, 53].

The copper (II) complexing ability of " Tris " buffer, routinely used in biochemical work, has been examined as a function of pH. Preliminary results indicate that " Tris " does have complexing ability and may compete with biochemical sites for available copper.

Studies conducted in cooperation with the Department of Soil Organic Chemistry have continued into the contribution to humic acid structure made by various plant components (lignin, ethanol soluble matter), in relation to the observed free radical signals. Work has centred around horizons of a natural podzol profile under pine trees.

Investigations into molybdenum complexes of humic substances have been completed and the results published[54]. It was shown that Mo(VI) is reduced by humic acid to Mo(V) and, to a much lesser extent, to Mo(III). In the case of soil polysaccharides, only the Mo(V) oxidation state could be detected.

Three projects have been carried out in collaboration with the Institute of Marine Biochemistry. The studies on copper(II) centres in ceruloplasmin reported last year (Annual Report No. 51) are now complete[55]. The results show that with plaice ceruloplasmin, the oxidase activity is located at one type of copper(II)-containing site, and that a second type of copper(II)-containing site reported by other workers for mammalian ceruloplasmin, is probably an impurity phase which can be removed by gel-filtration but not by affinity chromatography.

Work on the distribution of vanadium in sea squirts (*Ascidia Mentula* and *Ascidia Aspersa*) has now been completed and the results published[56].

A third project on the form of copper and its distribution in oyster blood (Annual Report No. 50) is still continuing. The properties of the copper binding ligand are being investigated using biochemical techniques and EPR. Purification has been carried out using gel-exclusion and metal-chelate chromatography and the copper(II)-containing component isolated in a 500-2000 M.W. fraction. Nitrogen superhyperfine structure has also been found in frozen solution spectra and attempts to simulate this using computer techniques are being carried out.

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4. SOIL ORGANIC CHEMISTRY

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The main objectives of the Department are to establish the nature, origins and properties of the organic components in soil, access the transformations that occur under different environmental conditions or management, and examine their effects on plant nutrition and growth. Some components release nutrients such as nitrogen, sulphur or phosphorus, some affect the solubility, transport and uptake of bio-essential trace elements, and some affect enzyme systems associated with plant growth. Organic components also play an important part in improving or maintaining good soil physical conditions for crop production. Other investigations involving chemical or physiological techniques are also being carried out jointly with organisations such as the Scottish Colleges of Agriculture, Aberdeen University, and the Department of Agriculture and Fisheries for Scotland. Experiments are carried out in the laboratory, in the glasshouse and in the field, and most are in close collaboration with other Departments in the Institute.

As an aid to our work on nitrogen, a Gilson gradient high performance liquid chromatograph, equipped with both a fluorimetric and a U.V. detector and interfaced to an " Apple " microcomputer has been acquired and amino acid analyses are now being carried out with this instrument. Increasing use of microcomputers is also being made for data processing and storage.

Chemical Nature and Properties of Soil Organic Matter

Humic Substances. In the traditional method of fractionation of soil organic matter, an alkali extract of soil is acidified with hydrochloric acid giving a precipitate of acid-insoluble humic acid and soluble fulvic acid. The humic acid is redissolved and both fractions dialysed before further analysis. Such a division is somewhat arbitrary and the composition of the fractions can be affected by such factors as the conditions of the alkali extraction, the sesquioxide content of the soil and the final pH. An alternative fractionation technique consists of acidifying the alkali to pH 3 with a protonated cation exchange resin, a process which does not precipitate any organic matter from solution. Such an extract contains low molecular weight components which would be lost by dialysis and already a series of aliphatic 2-hydroxy carboxylic acids has been identified, together with phenylacetic acid and other products previously identified after incubation of couch grass roots in soil (Annual Report No. 50, 1979/80). The yields of

phenolic acids released on hydrolysis are also higher with a relatively greater ratio of 4-hydroxybenzoic acid to vanillic acid. The extract is salt-free and should be in a suitable form for subsequent chromatographic fractionation. 304

Metal Complexes. In collaboration with the Department of Spectrochemistry, an examination has been made of the nature of the complexes which molybdenum forms with humic acid, using electron paramagnetic resonance spectroscopy. Under acid conditions molybdate was reduced by humic acid to Mo(V) and to a much lesser extent to Mo(III). This is the first definite evidence for the formation of Mo(III) in a natural substance. The spectra showed that two complexes were formed between humic acid and Mo(V). In the case of a soil polysaccharide only Mo(V) was detected[1]. 203, 307

Polysaccharide. The role of soil organic matter in binding soil particles together into stable aggregates or crumbs is well known, but there is still controversy about the components principally responsible and the mechanisms involved.

The contribution made by polysaccharide has in the past been assessed by comparing aggregation before and after a treatment with periodate which was thought to destroy carbohydrates, but did not always have a marked effect on aggregate stability. In a collaborative study with the Department of Microbiology, we have now shown[2], in all soils so far tested, that this treatment for 6h with 0.02M periodate does not destroy all the carbohydrate and even after much longer treatments with stronger periodate as much as 40% remains. The residues become relatively richer in glucose, arabinose and xylose, sugars typical of plant materials, and it is possible that they exist in the form of relatively large plant fragments physically protected in some way from chemical attack. Measurements have been made of microaggregate stability and residual carbohydrate after progressively longer treatments with sodium periodate and tetraborate. With Countesswells Series soil, there is a highly significant linear relationship between these two parameters suggesting a direct casual relationship between polysaccharide and aggregation. Similar relationships have been observed for a number of other soils under various agricultural regimes. 305, 512, 5613

In collaboration with the Department of Mineral Soils, studies have continued on the chemical structure of soil polysaccharide. The most effective extractant for the fraction is sodium hydroxide but there is a risk of artifact formation with this reagent. An alternative approach is being examined in which the soil is treated with a methylating agent, yielding a methylated polysaccharide which is soluble in chloroform. A single methylation, using the Hakomori method, released only about one quarter of the carbohydrate in soluble form but more was released with repeated treatments and after seven methylations the yield of sugars amounted to 70% of the sugars in whole soil hydrolysates. The identity of the methylated sugars released on hydrolysis was established by gas chromatography-

mass spectrometry and the positions of the unmethylated hydroxyl groups showed where the linkages occurred between sugars in the original material. In both hexose and pentose constituents, 1-4 linkages predominate, but there are considerable amounts of 1-3 linkages as well. The high proportion of sugar residues with two or more unmethylated hydroxyls suggests that there is a high degree of branching and/or substitution by other groups such as amino acids, and it is noteworthy[3] that the methylated product contains about 2%N. 108, 208, 305

The abstract of a lecture dealing with the structure and function of soil polysaccharides[4], and a paper on their fractionation[5], have been published during the year.

Other joint papers on the transformation of ^{14}C-labelled glucose in soil[6] and the effect of living plants on the rate of decomposition of organic matter in soil[7] have also appeared. 305, 512

Fungal material. Co-operative work with the Departments of Microbiology and Spectrochemistry has continued on the nature and properties of humic-like materials of fungal origin prepared from ^{14}C-labelled cultures. Fractions corresponding to soil humic acids, isolated from spores of *Coniothyrium minitans* or *Aspergillus niger*, or sclerotia of *Rhizoctonia solani*, were incubated in fresh soil at 20°C and the rate of loss of radioactivity was monitored. After three months 15% had been lost, rising to 20% in six months, but there was no further detectable loss after nine months. Humin-like material was of comparable stability, resembling that of humic acid and humin isolated from a Countesswells Series soil (Annual Report No. 51, 1980/81). A paper comparing the infrared spectrum of soil humin with spectra of other soil humic substances and fungal pigments has now been published[8]. 208, 301, 515

Soil Organic Matter and Plant Growth

Soil Enzymes. The activities of the enzymes amylase, invertase, dehydrogenase and phosphatase are being monitored under different agricultural crops. They are always highest at the beginning of the growing season in early May, then subsequently fall until late August when they increase once more. The activities of all four enzymes are the same under barley, potatoes, ryegrass and peas and are considerably higher than in fallow soils. 311

There are wide discrepancies in the methods described in the literature for measuring soil phosphatase activities and a paper reviewing these and making recommendations about assay conditions has been accepted for publication[9]. Another paper dealing with the assay of invertase activity in a range of Scottish soils varying in pH from 4 to 8, is being prepared for publication, and a paper describing the effects of humic acid on the generation of the superoxide radical (Annual Report No 51, 1980/81) has been published[10]. 311

Phenolic Acids. Investigations have continued on the effects of simple phenolic acids on plant growth. Initial field observations indicated an increased crop yield, but no significant effects were found this year. The amounts of individual phenolic acids varied under different crops but the differences seem to be unimportant in relation to growth. Even where the soils were treated weekly with a solution of 4-hydroxybenzoic acid, the yields of barley and peas were the same as in control plots receiving no additions. In solution culture, 10^{-5}M concentrations of these compounds stimulated growth, where 10^{-3}M and even 10^{-4}M concentrations are growth inhibitory. But, the inhibitory effects can be ameliorated in the presence of increasing amounts of nutrients such as phosphorus. In addition, in soil, some microorganisms can use phenolic acids as substrate (Annual Report No 51, 1980/81) and it is possible that the concentration of the acids near the roots is quickly reduced to very low levels. 311

Humic Acid. Further investigations have been made on the effects of soil organic components, particularly humic acid, on plant metabolic processess associated with growth. In an earlier study it was found that humic acid inhibits the formation of the amino acid hydroxyproline in the cell wall structure of pea roots, a possible mechanism for its action in enhancing root elongation. With beetroot storage tissue, in contrast, it increases the formation of the bound hydroxyproline. In the latter case it may be increasing the activity of the enzyme responsible for the hydroxylation of proline, because it has been shown to have such an effect on a number of other plant enzymes[11]. 311

Organic Nitrogen. Techniques have been developed for the analysis of amino acids and nucleic acid fragments by high performance liquid chromatography using a Gilson Model 42 chromatograph. With the amino acids, *ortho*-phthalaldehyde derivatives are first formed, then separated by reverse phase chromatography. At present, the derivatives can only be prepared from primary amines, so that proline and hydroxyproline cannot be estimated, but this problem is being studied. This method is more rapid than separation on exchange resins and has the advantage that the same system can be used both for physiological fluid samples and soil hydrolysates. The same buffers and reverse phase columns are also being used to separate nucleic acid bases and nucleosides, and phenolic acids. Chromatographic conditions for these and other separations are stored on " floppy discs " and different methods can quickly be set in motion.

Grass and soil samples are being analysed for protein-N and amino acid composition by a proposed EEC method for animal foodstuffs. To minimise losses, cysteine and methionine residues are oxidised prior to hydrolysis and are subsequently measured as cysteic acid and methionine sulphone. In soils appreciable amounts of cysteic acid can be detected prior to any oxidation step indicating the extent to which chemical or biological oxidation has occurred. 303

A paper dealing with the relationship between free amino acids and nickel in *Alyssum bertolonii* has been published[12]. 303

Other Investigations

Micronutrients. As part of a collaborative study on factors affecting the availability of micronutrients, and of relationships between soil values and plant uptake, comparisons are being made of the amounts of trace elements extractable from the rhizosphere of spring barley and those from adjacent bulk soil samples. Where compound fertilizer containing ammonium is combine-drilled with the seed, the pH of the soil associated with the roots is as much as 0·5 unit lower than elsewhere. This pH drop is accompanied by an increase of up to three fold in water-soluble manganese, but there is no significant difference in zinc or copper. The increased extractability of manganese in acidified rhizosphere soils has been observed previously and can be explained in terms of the depressed affinity of soil surfaces for uncomplexed micronutrient cations under more acid conditions. Manganese exists in soil solutions mainly in an uncomplexed form so that its concentration is pH dependent. Soluble zinc is also largely uncomplexed in Scottish soils and would thus be expected to behave in a similar way. That it does not do so is, as yet, unexplained. Soluble copper, in contrast to manganese and zinc, is largely complexed by organic ligands in the soil solution. The fact that the concentration of copper in the soil solution was not influenced by rhizosphere acidification is in agreement with previous observations that such complexes are not appreciably adsorbed on soil surfaces.

The lack of significant differences in soluble zinc and copper between rhizosphere and bulk soil also suggests that, in these circumstances, substances released by plant roots or rhizosphere microorganisms are of little importance in the mobilisation or retention in solution of these nutrients.
309, 609, 5206

Papers on some of the properties of complexes between copper and polycarboxylates isolated from soil solutions[13], and on the uptake of vanadyl-vanadium by wheat plants[14], using electron paramagnetic resonance spectroscopy, have now been published. 203, 309, 604

A paper on the effect of copper and nitrogen on the amino acid composition of oat straw has also appeared[15]. 305, 401

Co-ordination of Seedling Growth in Response to the Environment. Work in this field has continued, much of it in co-operation with the Departments of Botany and Genetics of Aberdeen University.

Seedling emergence through the soil surface is not a consequence of germination in a fortuitously appropriate orientation but of the seeding's success in distinguishing up from down and then making the necessary adjustments. Its ability to do this promptly is crucial to successful crop establishment yet after a century of investigation the mechanisms involved are still only partially understood. Papers referred to in last year's report dealing with aspects of this problem, viz, the kinetics of seedling growth[16], the analysis of growth during hook opening in the emerging seedling[17], and the analysis of growth during phototropic curvature[18], have now been published.

In the past year considerable effort has been deployed in automating the analysis of seedling growth under carefully controlled conditions. This has involved supplementing cinefilm recording of seedling growth with video tape which offers several major advantages, not least the fact that it allows virtually instant read-out of zonal growth measurements on either side of the entire length of a seedling hypocotyl. The equipment currently in use

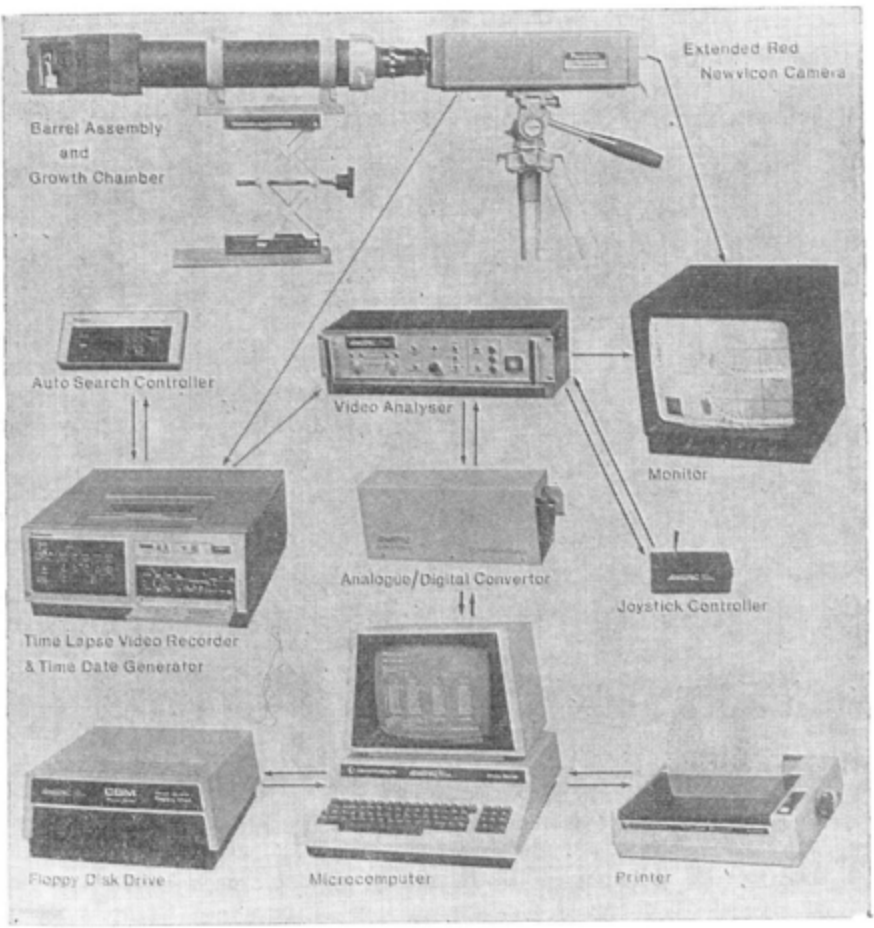

Fig. 4.1.
Video system for analysis of seedling growth and development.

in this work is illustrated in Fig. 4·1. A video camera registers on a monitor (either directly or via a time-lapse recorder) an image of the test seedlings suitably marked with resin beads. The displacement of the resin beads relative to each other as a consequence of growth may then be followed using the joystick controller which pinpoints the location of the beads by means of intersecting horizontal and vertical cursor lines activated by the video analyser. This information is then digitised and the zonal

growth rates printed out at selected times. A computer program for this purpose has now been written.

A major influence on the regulation of seedling growth is the Earth's gravitational field and the kinetics of hypocotyl curvature in response to gravity have been analysed using time-lapse photography. This study has shown that horizontal positioning of plant stems results in major disturbances in growth rates. Growth on the upper surface is severely inhibited while that on the lower surface is promoted. This differential growth brings about curvature as shown in Fig. 4·2. An account of this work and its implications with regard to traditional views of geocurvature has been submitted for publication[19].

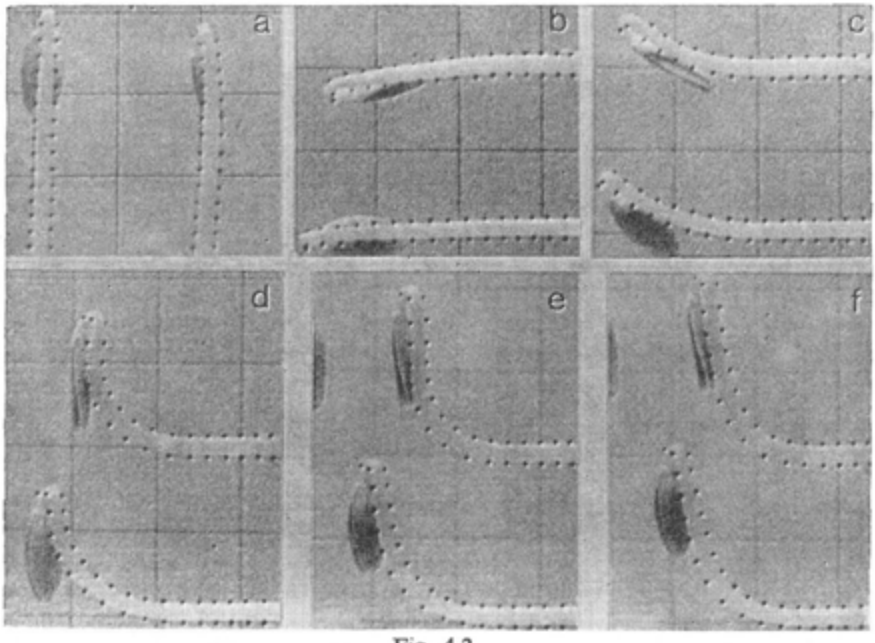

Fig. 4.2.
Time-lapse sequence of geostimulated cress seedlings showing the movement of curvature down the hypocotyl.

The role of the apex in the regulation of tropic growth and also the extent to which chemical messengers may or may not be involved in seedling curvature is a topic of current interest and considerable importance inasmuch as many growth-regulating chemicals extensively used in agriculture are thought to interfere with the transport of growth hormones in the plant. Experiments now in progress point to a decisive role of the apex in co-ordinating the response of the hypocotyl to different external stimuli. Under appropriate conditions growth can be induced in a basal region of the hypocotyl where growth has ceased. This resumption of growth appears to be under the control of the apex and the contribution of the epidermal cells of the hypocotyl seems less decisive than has recently been suggested.

The work reported last year on apical hook opening has now been extended to include a study of factors controlling the formation of the hook. Contrary to what is often envisaged, the hook does not emerge *ab initio* from the germinating seed, but is formed in the course of the emergence of the plumule. Evidence from ageotropic mutants and from experiments designed to neutralise the influence of gravity or to inactivate the mechanisms of perception indicate that gravitational signals are closely involved in hook formation. This emphasises the interesting situation that the apical end of the hypocotyl emulates the root in developing a positive reaction to gravity.

The use of resin beads as markers has allowed detailed studies to be carried out on the effect of growth-regulating chemicals on the kinetics of growth and a better understanding of the growth process has been obtained. For example it has been demonstrated that a concentration of morphactin, which apparently has no effect on the overall growth rate of a seedling, has a very significant effect on the region contributing to the overall growth of the seedling. It is obvious that this approach has much to offer in the elucidation of the effects of agrochemicals on seedling growth. 309

Ochre in Field Drains. During the year collaborative work began with the Departments of Microbiology and Soil Survey on the ochre problem in field drainage systems. This often arises when a waterlogged site is newly drained and can give trouble for many years subsequently. Iron is brought into solution in the form of a ferrous salt which is subsequently oxidised to the ferric form and precipitates as a sludge, quickly blocking the drains. Our approach to this problem is to remove the ferrous iron from solution prior to oxidation, utilizing the tannins in the bark of conifers. Ideally such bark should contain minimum amounts of water-soluble tannins because these might cause an environmental problem if released into water courses. Laboratory experiments have shown that Scots pine, Norway spruce and Sitka spruce are excellent sources of bark, whereas oak bark contains considerable amounts of water-soluble tannins. Ferrous iron is rapidly absorbed by the bark, up to 65mg by lg of dry material, and is not readily desorbed by water. The bark also acts as a filter for any ochre already present in the running drainage water.

In field trials at a farm near Turiff, the bark, contained in nylon mesh sacks, has been placed in inspection pits in the drainage system in such a position that the drainage flows through freely. At this location the drainage water contains from 2 to 80μg iron per ml, depending on the recent rainfall, but even after six months the bark still had the capacity to remove iron. When inspection shows that the sacks are losing their effect, they are replaced by fresh bark. With the co-operation of DAFS, trials at other sites in Scotland are now being set up. 116, 311, 503

Plant Enzyme Studies. Collaboration has continued with the Department of Plant Physiology in their investigations on the factors influencing the development of superoxide dismutase in fronds of the duckweed *Lema gibba* L. The growth hormone benzyladenine enhances the growth

of *Lemna*, but decreases the superoxide dismutase activity. In contrast, abscisic acid decreases growth and enhances the activity of the enzyme, and its effects are not abolished by adding equivalent amounts of benzyladenine to the culture medium. Superoxide dismutase in Lemna is a Cu-Zn metalloprotein which is very sensitive to Zn deficiency (Annual Report No. 51 1980/81). Benzyladenine inhibits the amount of Zn uptake into the tissue and this probably explains its effect on the activity of the enzyme.

A paper dealing with the localisation and properties of *Lemna* superoxide dismutase has now been published[20]. 311, 401

Podzol Formation. A joint paper re-examining the factors leading to the development of podzols has now been published[21].
201, 207, 208, 304, 801

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5. PLANT PHYSIOLOGY

P. C. DeKock

Active Iron

In previous work on this component of plant leaves, etherised tenthmolar hydrochloric acid was employed as extractant. The extract was then evaporated, ashed and the iron estimated colorimetrically. The fraction extracted thus is known as "active iron". A new extractant, o-phenanthroline in 3·5M hydrochloric acid can be used to extract this fraction and the colour complex obtained can be used for the determination of the iron without additional procedures.

As linear relationships between the "active iron" fraction and the amount of chlorophyll have been demonstrated, any factor affecting the active iron fraction should also affect the chlorophyll content, and changes in chlorophyll may similarly be reflected in changes in the active iron fraction. Moreover the relationships of phosphorus, potassium and calcium to the active iron fraction have been established. Thus the reasons why calcium deficiency[1, 2] causes a chlorosis in young leaves, while potassium deficiency is most apparent as a browning of the old leaves can be related to the active iron fraction being decreased in calcium deficiency and increased by potassium deficiency, the dark green leaves of phosphorus deficiency being similar to potassium deficiency.

The ferrous-ferric balance[3, 4] in the leaf must again be reflected in the active iron fraction as this fraction must be related to a ferrous iron species probably chelated by phenols in quinonoid linkages which are less stable than the nitrogen links in the o-phenanthroline complex. Ferrous ions also form complexes with thiol groups and consequently sulphur deficiency will tend to reduce the amount of active iron and so induce chlorosis. Chlorosis due to nitrogen deficiency can be explained by the fact that proteins are the essential components of the redox system and may involve several subunits of one complex molecule.

Chlorosis due to deficiencies of trace metals may be explained in terms of their effects on the redox system. Certainly both manganese and copper[5] are part of the redox system and deficiency of either generally means that the leaf showing deficiency is either dark green or has the reddish tinge of iron toxicity. The function of zinc can now be adequately accounted for in that it is part of the enzyme superoxide dismutase[6], the enzyme which causes superoxide radicals to combine with protons to form hydrogen peroxide which can then be broken down by catalase. Chlorosis due to zinc deficiency has been found to depend on the level of phosphate and a P/Zn ratio has been used to assess the zinc status of the plant, but more

probably the underlying cause of zinc deficiency chlorosis is due to an alteration of the redox state of iron through superoxide dismutase. Experiments to test this hypothesis are in progress.

It is well known that rapidly growing tissues are pale green in colour while mature or ageing leaves are dark green. Hence growth promotors such as benzyladenine depress while growth inhibitors such as abscisic acid increase active iron.

Criteria of toxicity can similarly be related to the active iron fraction[7]. The dominant effect of aluminium is to depress the phosphorus content of the cell and as such must cause an increase in active iron. Toxicities of other elements are explained by their effects on the particular element which they displace from the enzyme complex. In the case of cadmium this is zinc[8]; the results of our experiment supporting such ideas have been presented and are being prepared for publication.

Early studies by Bolle-Jones (Plant and Soil VI, 129-173, 1955) on the relation between iron and potassium in the leaves of the potato plant, indicating a synergism between the two elements appear to be at variance with the above ideas, but closer scrutiny suggests that there are certain misinterpretations in his study. More exact interpretations of his results have been obtained by computer analysis and those are, in general, not at variance with our views. This work is being prepared for publication.

Physical factors such as water deficit[9] and other environmental stresses should be reflected in the active iron fraction as also should physiological processes such as ageing, varietal differences and other genetical effects. This approach appears to have great promise for the future, because optimum growth means that all factors must be kept at optimum levels for maximum yield. Inevitably these concepts lead to considerations of balances between ions and strongly support our early ideas. 401, 402, 408

Nitrogen flux studies

Ion flux studies at the cellular level, using onion root segments, have been extended to an examination of ammonium and nitrate fluxes, using ^{15}N enriched salts. Roots were grown and root segments incubated in complete nutrient solutions containing either sodium nitrate or ammonium sulphate (2mequiv. l^{-1}) as the sole nitrogen source. In other respects, the nutrient solutions were similar to the "1x" solution used in previous ion flux studies.

Estimates of atom % ^{15}N in our root samples were obtained using an optical emission spectrometer built in the Institute. To measure efflux, however, estimates of ^{15}N in initially unenriched nutrient solution, used to wash the root segments, were required, and the enrichments obtained were too small to be reliably measured by the optical emission method. Instead, the washing samples were analysed by mass spectrometer, thanks to the willingness of Dr David Jenkinson and his staff in the Department of Soils and Plant Nutrition, Rothamsted Experimental Station, to provide this service.

A limitation of both methods of N isotope ratio estimation is that a minimum sample size of 1mg N is desirable. For onion roots, about forty 4cm segments are required to obtain sufficient nitrogen, and since the digest needs to be steam distilled in two batches to avoid "memory" effects in the still, 80 segments constitute the minimum sample size. This number of segments makes it impractical to run experiments in which transported N can be isolated from surface efflux, and so the data presently obtained fail to make this distinction. The number of root segments required to provide a sample for N isotope ratio estimation can be reduced by addition of known amounts of unenriched N to the distillate but at present, to reduce the segments in a sample to a manageable number, such additions would require to be unacceptably large.

The determination of ammonium fluxes has been hampered by the commonly encountered difficulty of rapid drift to a very acid pH in solutions in which NH_4^+ is the only nitrogen source. Some attempts were made to overcome this by inclusion of ion exchange resin, previously equilibrated with nutrient solution, in growth solutions and in incubation flasks. The effect on pH stabilization was small and short-lived, and ^{15}N enrichments became much reduced from nominal values due to exchange. Thus, ammonium flux data obtained so far relate to solutions in which the pH was commonly as low as 3·5.

The above limitations notwithstanding, some interim findings can be reported, Over 24 hour, uptakes of NH_4^+ and NO_3^- were similar, amounting to 30-40μmoles N g^{-1} (fresh weight). Continued incubation of the root segments showed little further increase, and sometimes a small reduction from this level. During the first 6 hours incubation, ammonium uptake was much faster than nitrate uptake, so that the latter gave an exponential relationship (up to 24 hours), indicating an initial lag-phase following excision, whereas ammonium uptake *versus* time gave a hyperbolic relationship. After 17 hours incubation half-times of exchange ($t\frac{1}{2}$) for each ion in the cytoplasm were similar (about 60-70 minutes), but $t\frac{1}{2}$ between vacuole and outside medium was faster for NO^-_3 (60 hours) than for NH_4^+ (200 hours). In common with Ca^{2+} and Mg^{2+}, NH^+_4 exhibited a Donnan free space exchange component ($t\frac{1}{2} \simeq 18$ minutes).

This work on relative uptake and exchange rates of nitrate and ammonium in roots was initiated with a British Council Scholar from Argentina whose visit to the Department started in October 1981. This collaboration came to an untimely end with the conflict in the South Atlantic, but it is intended to proceed with this work as time and staff allow. Measures are in hand to overcome the difficulties with pH control, and to circumvent the problems in the measurement of transported N. The work promises to provide much information useful in connection with nitrogen studies underway in several other departments. 407

Trace element uptake and transport

In view of the continued problems of trace element deficiencies in animal diets, experienced by livestock farmers, it is planned to expand this

aspect of the work. Flux and transport studies, using ^{58}Co, have been started, using wheat root segments, in parallel with work on whole wheat seedings in the Department of Soil Organic Chemistry. 407

Potassium absorption and transport

A paper[10] has been submitted for publication reporting the results of a study of the effects of "crown" polyethers on uptake and transport of potassium in wheat and mung bean seedlings. This work, accounts of which have appeared in Annual Reports 50 and 51, was carried out in collaboration with the Molecular Structures Department, Rothamsted Experimental Station. 407

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6. MICROBIOLOGY

J. F. DARBYSHIRE

As in previous years, the current research of the Department has been mainly concerned with the transformations of plant and microbial organic matter in the soil and with the consequences of these transformations for plant roots. Greater co-ordination between individual research projects has been achieved, however, during the past year. For example, since the termination of the project specifically concerned with nitrogen-fixing bacteria associated with cereal roots, attention has been focussed on the reserve of nutrients (N, P, K, minor and trace elements) in the microbial biomass in both organic and mineral soils. Studies have begun of the conditions favouring the release of these nutrients into the soil, either as a result of lysis or predation by secondary decomposer organisms (e.g. protozoa), and subsequent nutrient assimilation by the roots of agricultural plants and tree seedlings. Such investigations should improve the understanding of the mode of transfer of nutrients from either inorganic or microbial fertilisers to plant roots. These studies have required increased co-operation with the Departments of Peat and Forest Soils, Soil Organic Chemistry and Spectrochemistry. The new cold stage and cryotransfer attachment for the existing scanning electron microscope in the Pedology division should prove to be a very useful aid to the study of nutrient assimilation by plant roots in soil (Fig. 6·1).

Interrelationships of Plant Root and Microbes

As described in the previous Annual Report, nitrogen fixation by free-living nitrogen-fixing bacteria adjacent to plant roots had no significant effect on the nitrogen content of a range of cereals in Scottish soils. It was concluded that the major limiting factor was a shortage of carbohydrate in the rhizosphere[1, 2]. This investigation, however, did show that a large inoculum of microbial cells could provide a satisfactory source of nitrogen for maize and wheat plants. The assimilation of such microbial nitrogen was followed using cells labelled with ^{15}N. Microbial nitrogen was mineralised very rapidly after it was added to soil and it was assimilated by wheat plants almost as quickly as nitrate nitrogen. Up to 80% of the microbial nitrogen was recovered in the wheat plants. The contribution of nutrients in the microbial community in the soil to plant nutrition is at present unknown, but these experiments suggest that large amendments of microbial cells may be used as organic fertilisers. The economic feasibility of such a proposal depends greatly on selecting a range of suitable micro-

organisms, which can degrade either agricultural, industrial or domestic waste and fix atmospheric nitrogen. Some of these results were reported at a recent meeting of the Society for General Microbiology in Dundee and a detailed account will be published soon[3]. 513

The rates of mineralisation of phosphorus compounds from a range of microbial cells have also been investigated in several laboratory and glasshouse experiments. As in the nitrogen studies mentioned earlier, there is a rapid mineralisation under most soil conditions and a wide range of crop plants can obtain their phosphorus requirements from microbial cells. 513

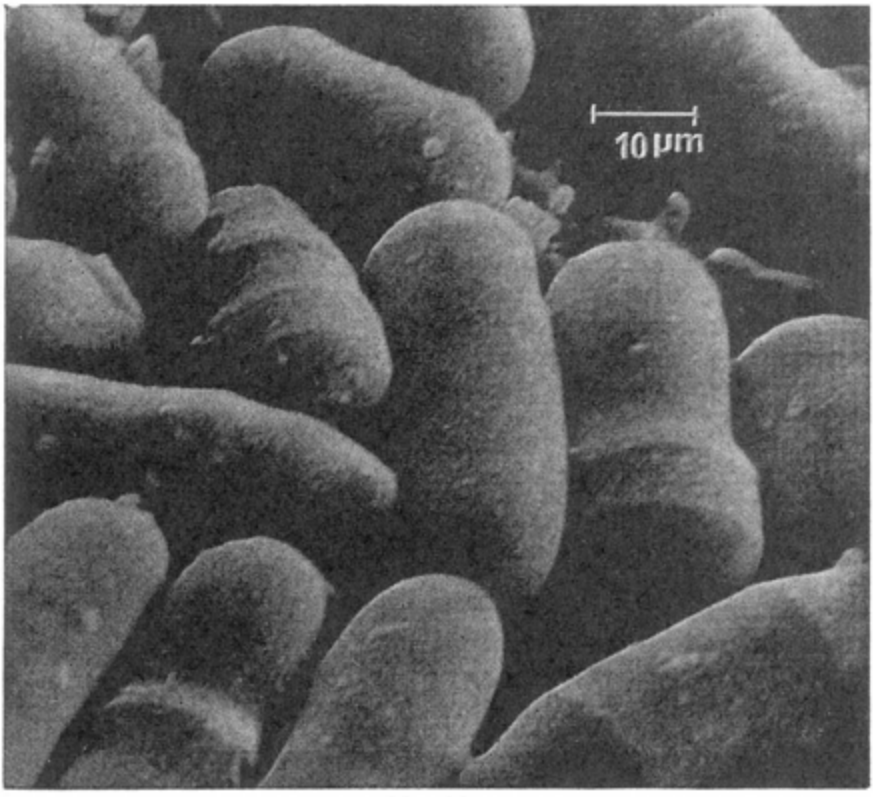

Fig. 6.1.

Scanning electron micrograph of *Schizosaccharomyces pombe cells* showing very distinct division scars. The specimen was quench-cooled in liquid nitrogen, then sputter-coated with gold and examined at 20Kv on the cryogenic stage (−87°C) of a Hexland Cryo system.

Fungi

Ultrastructure. Studies with the Department of Soil Organic Chemistry on the ecology and physiology of soil fungi capable of decomposing phenolic acids have continued. Many of these phenolic acids are phytotoxic and electron microscopy has often been used to assist in the correct identification of these fungi. For example, a joint paper has been published with

the Curator of the Culture Centre, Commonwealth Mycological Institute describing ultrastructural features of one of these fungal isolates, *Acremoniella velata* sp. nov[4]. A culture of this fungus has been deposited in the American Type Culture Collection. Another fungal isolate, *Stilbella bulbicola* P. Henn., has recently been examined in the scanning electron microscope. The results of this study have been accepted for publication and contain observations on the asexual fruiting structures, which supplement the original description by Hennings in 1905. A culture of *S. bulbicola* has been deposited in the Culture Collection, Commonwealth Mycological Institute, Kew (IMI 259852). Another common isolate during these studies is the fungus, *Gliocladium roseum* (Link.) Bainier. This fungus has also been examined in the scanning electron microscope and the results of this study are being prepared for publication. 516

Mycetozoa and Protozoa

Some of the cinemicrophotographical studies of amoeboflagellates of members of the Cavosteliidae described in the previous Annual Report have been accepted for publication[6]. The most surprising discovery recorded by these cinefilms was that the flagellates move faster than the corresponding amoeboid phase, although the flagella seem to function solely as tactile organelles. Transformation into the flagellate phase and increased motility after an increase in soil moisture may be an important attribute to microorganisms seeking to feed on the microflora in new microenvironments. 510

In collaboration with the Department of Soil Survey suitable methods have been developed for characterising the network of soil pores, which are inhabited by soil protozoa. These methods, which involve the use of serial sections of soil and a computer program are discussed in section 9. In the future, it is hoped to use these methods to relate the size of protozoan populations to the nature of their microenvironments, as represented by the pore network and continuity of the soil pores, in different horizons of one profile and in similar horizons in different soils. These methods are being prepared for publication and may be of use to soil scientists interested in gaseous diffusion and the movement of plant nutrients or water in soils. 510, 804

Efforts have been made to find a more reliable and rapid method for estimating the trophic population of soil protozoa than the current HCl method. These investigations indicated that dilute HCl kills a proportion of the cystic protozoa as well as the trophozoites and the sonication of the soil suspensions also seems to be unsatisfactory. The search for a more satisfactory method will be continued. 510

Organic Matter

Microbial synthesis. A paper describing the possible contribution of fungal melanins to the humin fraction of soil has been accepted for publication[7]. This investigation is a joint project with the Department of Soil Organic Chemistry and Spectrochemistry and is relevant to the survival of certain important fungi in soils. 208, 301, 515

Polysaccharides. The effects of soil polysaccharides from plants and microbes on soil structure have been studied further with the collaboration of the Department of Soil Organic Chemistry. A linear relationship has been established between the water stability of soil microaggregates (circa 50μm diam., and the quantity of soil polysaccharide present. Selective oxidation and removal of polysaccharide using a periodate/tetraborate treatment decreased the stability of the aggregates. Analysis of the residual polysaccharide indicated that the microbial fraction had been preferentially oxidised and it is suggested that microbial polysaccharides have an important role in maintaining aggregate stability in soils. These results were presented at a recent meeting of the British Society of Soil Science and have been accepted for publication[8]. Papers dealing with the synthesis of polysaccharides by selected microorganisms in sterile soil and the effect of barley plants on the rate of organic matter decomposition, as discussed in the previous Annual Report, have been published[9, 10].

Biomass. The availability of the nutrients, particularly nitrogen and phosphorus, in the microbial biomass of organic soils to plants growing on these soils is being assessed. These investigations are collaborative studies with the Department of Peat and Forest Soils and involve forest and heath soils as well as waterlogged peats. It has been found that the biomass is greater in the drier forest and heath soils than in the waterlogged peaty soils. In addition, the biomass in the humus layer of forest soils varies markedly from one site to another and with the predominant tree present. For example, the humus under larch trees had a much larger biomass and greater metabolic activity than humus under Scots pine. 116, 512, 513

A joint study has been initiated with the Department of Spectrochemistry of the ability of soil microorganisms to accumulate certain trace elements. In the future, it is hoped to determine whether the elements released by microbial cells are more readily assimilated by plant roots than the residual trace elements in soil. 201, 512

Two papers concerned with a comparison of methods of estimating microbial biomass and the biomass in mushroom composts have been accepted for publication[11, 12]. Both papers were discussed in the previous Annual Report and resulted from collaborative studies with other research institutes. 512

One paper dealing with the effects of amendments of phenolic acids on the microbial biomass in soil has been published[13]. 311, 512

Microcalorimetry. The measurement of microbial activity in soils by microcalorimetry was discussed in a lecture at a recent meeting of the Society for General Microbiology and a paper dealing with the same topic has been accepted for publication[14]. 512

Biological Weathering

The joint project with the Department of Mineral Soils on microbial weathering continues to reveal important data on the possible mechanisms involved in releasing plant nutrients from soil minerals. Investigations of natural interactions, such as between rocks and lichens, are being supple-

mented with pure culture studies of soil fungi, including rhizosphere isolates. As earlier investigations had established (Annual Report 1980-81) that oxalic acid was implicated in these weathering processes, 150 species of soil fungi, were screened, using an agar plate technique, for their ability to secrete oxalic acid. The presence of bipyramidal crystals of calcium oxalate in the agar (Czapek Dox) around the fungal colonies was accepted as evidence that oxalic acid was released by the fungus. The majority of the positive isolates were species of *Penicillium* and *Aspergillus;* in some instances there was a profusion of crystals in the agar around fungi of these genera. It was particularly interesting to find masses of calcium oxalate crystals around colonies of a mycorrhizal endophyte, *Rhizoctonia goodyerae repentis*. Other workers have noted the presence of calcium oxalate crystals in association with mycorrhizal fungi and have commented that oxalic acid from fungi is involved in the release of phosphorus from iron and aluminium hydroxyphosphates. Two further papers reporting the results of these studies have been published[15, 16] and another awaits publication[17].

Further studies of lichens have revealed more interesting information about how microbes withstand large amounts of potentially toxic heavy metals. For example, it was found that when one of the crustose lichens, *Pertusaria corallina,* growing on manganese ore from the Lecht mines at Tomintoul was examined with a scanning electron microscope, manganese oxalate crystals were found to be abundant in the thallus. The nature of these crystals was identified by X-ray microanalysis and X-ray powder diffractometry. On present evidence, these manganese oxalate crystals result from oxalic acid from the mycobiont reacting with the manganese ore. These crystals also contain some zinc and the formation of mixed oxalate crystals may also be a mechanism whereby these lichens can withstand potentially harmful quantities of this metal. Further studies are in progress with crustose lichens colonising copper and lead ores from various parts of Scotland. A preliminary study of a lead-tolerant lichen, *Stereocaulon vesuvianum,* has indicated that large amounts of lead accumulate in the hyphae near the lichen/rock interface. The basic lead carbonate mineral, hydrocerussite, has been detected in the hyphal tufts by X-ray powder diffraction, together with traces of quartz, whewellite, calcite, metallic lead and various lead oxides. The results of this investigation have been accepted for publication[18]. 104, 109, 207, 516

A paper describing the use of a bacterial exudate, 2-ketogluconic acid as a soil extractant has been published[19]. The results were discussed in the previous Annual Report. 201, 202, 502

Peat Microbiology

The study of the bacteria in peat samples from the controlled water table experiment at Lon Mor near Fort Augustus has continued in collaboration with the Department of Peat and Forest Soils. The largest concentrations of inorganic nitrogen in the fresh peat were found in the horizons where the bacteria were most abundant; the lowest concentrations occurred where the bacterial populations were small.

The studies of peat composts have continued and increasing the pH of the peat with either lime or potassium hydroxide resulted in large increases in the bacterial populations and respiration. No increase in the amount of inorganic nitrogen was detected in the peat at any time during incubations for three months. 116, 503

A collaborative study of iron ochre deposits has started with the Departments of Soil Organic Chemistry and Soil Survey. These deposits are often found in blocked field drains on peaty soils. As recent reports from West Germany claimed that ochre deposition can be delayed by surrounding the drains with the bark of Australian Wattle, the barks of several British trees were examined for their capacity to absorb iron. Laboratory trials have shown that the bark of several native conifers can retain large quantities of iron. The chemical aspects of this reaction are discussed in Section 4, but these coniferous barks had little effect on the growth of iron oxidising bacteria. Field trials with native coniferous bark have started at sites in East, West and Central Scotland. At Keithen Farm, near Turiff, coniferous bark has been placed in the inspection pits of the drainage system at 50m intervals. After 6 months the drains are still free from iron ochre and the results are promising. A bacteriological survey of the surrounding organic and mineral soils has shown that iron precipitating bacteria are present in large numbers and are ubiquitous. 311, 503

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7. SOIL FERTILITY

B. W. BACHE

The Department is concerned with soil in relation to crop production. It's main aim is to understand how soil and environmental factors interact with plants to determine crop yield and composition and subsequently to recommend the most economic ways of controlling soil factors to obtain optimum crop and animal production. The Department is currently reorienting it's programme to bring the laboratory and field aspects of the work closer together, to give more importance to possible physical restrictions to root growth and function, and to this end it is negotiating for field sites on which long-term fertility experiments can be done. Apart from this research role involving soil chemistry, soil physics and crop sciences, the Department has an advisory role for farmers through the North of Scotland College of Agriculture.

During the year under review the Department has been represented on a number of committees and working groups: the Scottish Standing Committee for the Calculation of the Residual Values of Fertilizers and Feeding Stuffs, the Consultative Committee for the Development of Spectrochemical Work, the COSAC/SARI Trace Element Study Group, the COSAC/Macaulay Liaison Committee, the Scottish Committee co-ordinating the "Money from Grass '83 Campaign," the Trace Element Speciation in Foodstuffs Committee of the Royal Society of Chemistry, the Hill Land Use and Ecology Group, the North of Scotland Grassland Society Committee and the Biological Advisory Panel of the Central Electricity Research Laboratories.

Demonstrations of various aspects of the work of the Department have been given at the Turriff Agricultural Show, the Cultivations for Winter Cereals Open Day at SIAE and the North-Eastern Farmers Open Day.

Staff shortages are still causing problems, but Mr P. Wilson has been appointed to work on soil physics research. Dr R. Lee from the Soil Bureau, New Zealand, has completed his work on salt extractable aluminium in relation to the cation exchange capacity of soils. Mr Ji Guoliang from the Institute of Soil Science, Nanking, has been working on micro-faradic electrodes. Dr S. U. Patwary from Bangladesh has been studying soil water balances using neutron attenuation methods. Professor F. E. Koehler from Washington State University has been investigating the sensitivity of some USA wheat growing soils to acidification. Mr M. Hepher has completed his research studentship on piezoelectric crystal gas monitors and Miss S. Fraser is continuing work on the same topic.

Field Crop Sciences

Nitrogen for Winter Barley. Fifteen experiments have now been completed to investigate the form of the N response relationship of winter barley. All experiments have shown responses to spring-applied N consistent with the split line relationship described previously for spring barley (Annual Report Nos. 49 and 50). Up to an average rate of N application of 105 (range 80-140) kg/ha on sites with low-to-moderate N status, 1 kg of added N produced an average of 30 (range 20-50) kg/ha grain dry matter. Above 105 kg/ha the slope of the response line changed to 8 (range 4-14) kg/ha dry matter per kg of N applied. Maximum yields required at least 160 kg/ha in 1981 and at least 200 kg/ha in 1982. These maxima are probably underestimates as yield was still increasing at the highest N level tested in some of the experiments. Current recommendations for moderate and low N status soils of 80 and 120 kg/ha respectively, were clearly inadequate for 1981 and 1982. Both seasons were unusually warm and dry from spring to harvest time. This resulted in good ripening and harvesting conditions with little lodging leading to unusually high optimum N requirements for both winter and spring barley in these years.

Mean yields with optimum N rates were again very good, 7·7 t/ha of grain dry matter compared to 5·9 t/ha in 1981, equivalent to 9·0 and 6·95 t/ha of grain at 15% moisture. One experiment produced 10·3 t/ha of grain at 15% moisture.

In general, our results and those of other workers show an association between high yield and early sowing. However, there is little direct evidence for this relationship. Early sown crops tend to receive higher inputs of herbicides, fungicides and fertiliser. Three experiments were sown in adjacent blocks on 1st and 24th September, and 10th October, 1981, with various autumn N and 5 spring N treatments. The yields with 200 kg/ha of spring N were 7·52, 8·02 and 7·85 t/ha grain dry matter for the early, medium and late sown crops respectively. The yield response to nitrogen is shown diagramatically in Fig. 7.1. The result is rather different from commonly accepted belief and requires further verification. At lower rates of N, the pattern was reversed with yields of 7·2, 6·7 and 7·0 t/ha with 120 kg N/ha and 5·4, 3·8 and 3·5 t/ha with 40 kg/ha, for the early, medium and late sowing dates respectively. It seems possible that the yield potential of later sown crops has not been realised because of inadequate spring N applications. Several experiments have tested the effects of splitting the spring N dressing, usually applying half in early March and half in early April compared to a single application in mid-March. No consistent benefit has been seen to justify the extra cost of splitting the N dressing. Three experiments include comparisons of different times and/or rates of autumn N applications but in this season no substantial responses were found.

607, 5703

Manganese on Barley. The effects of manganese sulphate foliar sprays were measured on two winter barley crops on soils of pH (in water) 6·2 and 6·6. There was no significant effect at pH 6·2, but at pH 6·6 there were increases in grain yield of 0·40-0·56 tonne/ha dry matter when 4·5

kg/ha of $MnSO_4 \cdot H_2O$ was applied in 225 litres of water (with a wetting agent) at each of growth stages 15/16 and 31, and when 9·0 kg/ha was applied at growth stage 31.

The work comparing seedbed consolidation, method of fertilizer application, and spraying manganese sulphate, on the yield and grain quality of spring-sown barley has been reported in an advisory leaflet[1].

Seed treatment of barley with $MnSO_4 \cdot H_2O$ solution at rates equivalent to 4·5 kg/ha increased Mn concentration in the crop at growth stage 14/15

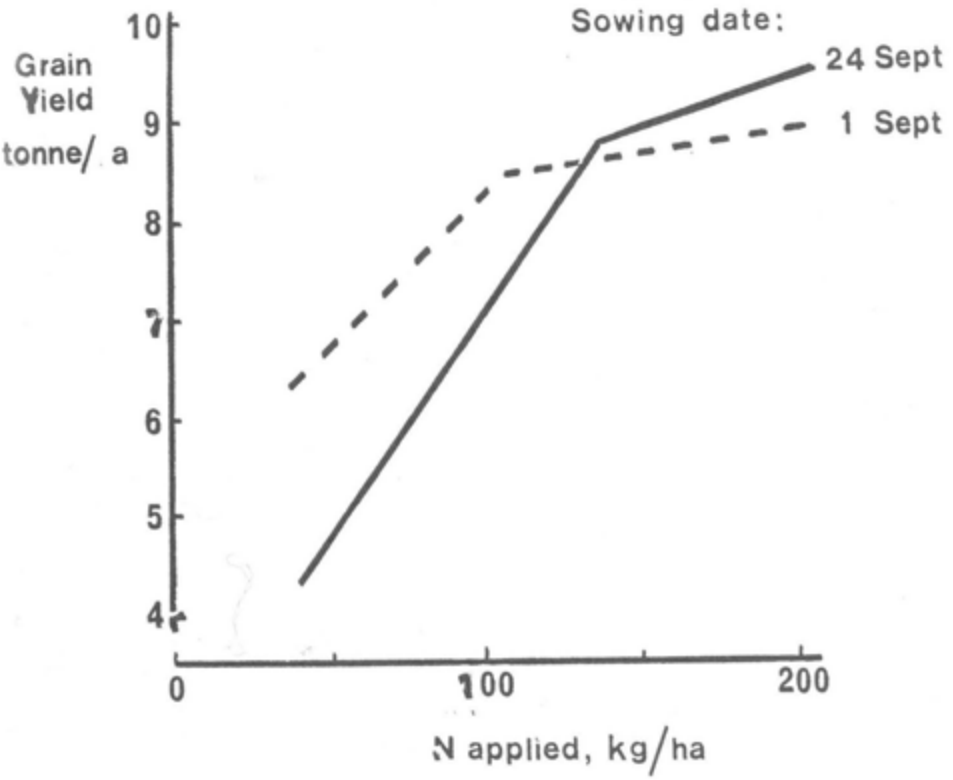

Fig. 7.1.
Effect of sowing date on the response of winter barley to spring applied nitrogen.

from 25 to 47 μg/g, compared with no treatment, and final grain yield from 3·40 to 4·26 tonne/ha dry matter. Foliar spray of 4·5 kg/ha $MnSO_4 \cdot H_2O$ gave a yield of 4·56 tonne/ha DM, and prior seed treatment had no effect in this case.

Combine-drilling ammonium nitrate-based NPK fertilizer with spring barley decreased soil pH in the rhizosphere soil, compared with broadcasting which reduced soil pH in the bulk soil. These decreased pH values increased the solubility of soil manganese, the greatest changes being about six weeks after sowing, while at eleven weeks after sowing the levels had nearly returned to the initial ones. Both Mn concentrations and total Mn

in plants at growth stage 14/15 were significantly correlated with soluble Mn in the rhizosphere at growth stage 12/13, but were negatively correlated with Mn in the non-rhizosphere soil. 609

Forms of Phosphate for Swedes. Up to about 1955 approximately half the phosphate in the normal NPK fertilizer for swedish turnips was in the form of ground mineral phosphate because earlier experiments had shown that this produced the same yield as water-soluble phosphate. In 1981, two experiments on slightly acid soils, pH 5·8 (H_2O), showed that powdered Gafsa (Tunisia) phosphate produced similar yields to approximately half the amount of applied P as triple superphosphate. The granular and chip forms of Gafsa phosphate were much less effective than the powdered form, their effectiveness being equivalent to about 10 and 15 per cent of the P as superphosphate, respectively. Where the phosphatic treatment was half superphosphate and half powdered or chip forms of Gafsa, the yields were similar to those produced by the water-soluble phosphate alone and showed practically no benefit from the water insoluble phosphate. These results support the current practice of applying all water-soluble phosphate for swedish turnips. 608, 5701, 5703

Forms of Phosphate for Grass. The effectiveness of Gafsa phosphate in commercial powdered, granular and chip forms was compared with granular triple superphosphate and basic slag in two field experiments on grass/clover leys and in one pot experiment with ryegrass. Lime was applied to raise the soil pH to about 5·8 and a basal application of 20 kg/ha of soluble P was given to establish the seeds. Just before the seeds were sown supplementary applications of 60 and 120 kg/ha P of the test material were broadcast in the field experiments and an application equivalent to about 80 kg/ha P in the pot experiment. Over three years in the field experiments, the yield of herbage dry matter from the basic slag treatments was 97 per cent of that from triple superphosphate while the powdered, granular and chip forms of Gafsa phosphate produced mean yields equivalent to 93, 89 and 90 per cent of that from superphosphate. In the pot experiment, the yield from basic slag was slightly higher than that from triple superphosphate while powdered Gafsa gave a relative yield similar to that in the field. However, the granular and chip forms of Gafsa were relatively less effective in the pots than in the field, producing about 85 per cent of the yield from superphosphate. These experiments show that granulating powdered Gafsa phosphate reduces its effectiveness, particularly in the year of application. Although it is no longer commercially available, Calcined Senegal Phosphate was also compared in these experiments, but its effectiveness was similar to that of powdered Gafsa phosphate. 608, 5701, 5703

Effect of Applied Nitrogen on Soil Acidity. The previous four Annual Reports described a collaborative ADAS/ARC grass-white clover experiment (GM23) in which annual applications of 0 to 600 kg/ha N were supplied as ammonium nitrate. The pH (H_2O) and acetic acid-soluble calcium contents were determined in soil samples taken at the beginning and end of the experiment. With 0 and 100 kg/ha N per year there was no

measurable change in soil pH over the four years, but calcium levels decreased by about 80 mg/kg soil <2 mm. With 200, 300 and 400 levels kg/ha N per year, the loss of calcium was slightly higher at about 100 mg and the soil pH fell from 6·1 to 5·9 with the 400 kg N treatment. At the 500 and 600 kg N rates, which produced only a marginally higher yield of dry matter than 400 kg N, there was a marked soil pH drop to pH 5.7 and 5.5, respectively, the corresponding decreases in calcium being 160 and 280 mg/kg soil. These results are in general agreement with those of an earlier experiment (Annual Report, 1976-77, No. 47) and show that nitrogen applied at optimum rates for the particular crop does not markedly increase the loss of calcium by leaching. 608, 5206

Trace Elements on Various Crops. The COSAC/SARI Trace Element Study Group, mentioned in last year's Report, completed its work during the year and the advisory Bulletin, Trace Element Deficiencies in Ruminants, was published in October 1982[2]. This Bulletin has major sections on trace elements in soils and plants, especially herbage, and summarizes the main findings from collaborative work with the Departments of Spectrochemistry and Soil Survey. 609

The effects of applying various trace elements on the yield of crops and herbage have been noted in previous Reports, and these results are gradually being evaluated for publication. A joint paper[3] presented at the BSAP/BVA Symposium on " Trace elements in animal production and veterinary practice " illustrated direct effects of applying trace elements to soils and the indirect effects of lime and NPK applications, mainly for cobalt, copper, manganese and molybdenum. The Co contents in herbage can be readily increased by applying 0·5 kg/ha Co as cobalt sulphate to the soil. On copper-deficient soil the yields of cereal grain, and sometimes pasture herbage, can be increased by applying 6 kg/ha Cu as copper sulphate; for cereals, this can remain effective for 20 years. Copper contents in herbage at the silage stage of growth are normally appreciably less than 10 mg/kg dry matter, even with applied Cu. The application of lime reduced the Cu content in cereal grain on a copper-deficient soil, but not on a copper-adequate site. Applying superphosphate reduced the Cu content in herbage. Broadcasting manganese sulphate on calcareous sandy soils (pH>7·0) increased grain yields marginally, but combine-drilling manganese sulphate with the NPK fertilizer was more effective than broadcasting. A single application of 0·9 kg/ha Mo as sodium molybdate markedly increased the Mo content in mixed herbage for at least 20 years. Another joint paper[4] with the Department of Spectrochemistry has been prepared for publication on the effects of fertilizers, especially N, and added cobalt, on the uptake of cobalt by mixed herbage and its individual main constituent species, cut at the silage stage of growth three or four times per year for at least three successive years. Without added Co, N applications increased Co content in herbage on peat, but reduced it on the mineral soils mainly by eliminating clover which had a higher Co content than grasses. As noted above, applying 0·5 kg/ha Co as cobalt sulphate increased herbage Co contents, the increase being greater on peat than on mineral soils. These increased levels

were unaffected by N applications on mineral soils, but were increased by applied N on peat. The number of years during which the Co additions were effective in producing herbage containing at least 0·1 mg/kg Co dry matter varied on the different soils, ranging from barely three years on one mineral soil to over five years on peat. Without added Co, the last cuts in October usually had the highest contents and the first cuts in June the lowest. With added Co, the seasonal effects were more variable, but the Co contents in the herbage frequently decreased from the first to the last cuts. 609, 201, 202

The long-term effectiveness of soil copper applications has been recorded in previous Reports and in one experiment the effectiveness of the residues of 0, 3 and 6 kg/ha applied as copper sulphate in 1964 were compared with 6 kg/ha Cu as copper sulphate applied in spring 1982 just before barley was sown. Where no Cu was applied in 1964, the 1982 copper treatment increased the yield of oven-dry grain by 0·6 t/ha while the residues of both the 3 and 6 kg Cu applications increased grain yield by an average of 0·5 t/ha. The 1982 Cu application to the plots treated with Cu in 1964, increased yields by only 0·1 t/ha. This experiment confirms that Cu applied to soil remains highly effective for many years. 609, 5701, 5703

A considerable amount of data has been accumulated on trace elements in soils, particularly from advisory samples and typical profiles from the Soil Survey. The availability of cobalt and molybdenum, and to a smaller degree copper, clearly depends on the natural pedological drainage conditions of the soil, and uptake of these elements by crops in adjacent soils increases as the drainage conditions change from free to imperfect to poor. This information is gradually being integrated with the objective of producing maps, based on the published Soil Survey maps, showing three categories of probable risk of cobalt deficiency and four categories of probable risk of molybdenum excess in relation to ruminant nutrition. For copper, the three or four categories of probable risk are for copper deficiency in cereals and the expected range of copper contents in summer herbage. 609

Sulphur for Herbage Crops. Experiments at two sites in 1980 and 1981 on mixed herbage swards showed that S additions gave considerable yield increases for the later cuts[5]. These have been continued in 1982 and have again shown a similar pattern of results. In 1982, experiments on a further eight grassland sites that were low in available S, gave yield increases at the second cut on plots that had received additions of S.

Crop Chemistry and Composition

Cation Exchange Capacity of plants. The cation exchange capacity (CEC) is a characteristic of each plant species. Many years' work to assess its importance in mineral nutrition has now been concluded. Mattson used the principles of the Donnan Equilibrium to show that plants of higher CEC should selectively absorb divalent ions rather than monovalent ions. Higher Ca/K ratios were found in legumes (high CEC plants) than in cereals, (low

CEC plants), to support this hypothesis. The object of the work here was to discover whether there was a general relationship between plant CEC and mineral nutrition that would hold throughout the plant kingdom.

A very wide range of plant material was analysed for CEC and for mineral elements. It included roots and tops of lower and higher plant samples, from fertilizer experiments and variety trials, grown on contrasting substrates such as peat, sand, acid and calcareous soil, and in water culture experiments. Tests grouped plants in various ways, such as single family, genus or species on a range of substrates, or all species on one substrate. The data failed to show a precise relationship of general applicability between CEC and cation selectivity. A relationship between Ca/K ratios and CEC may be obscured by other factors affecting growth, and because contents of all four major cations (K, Na, Ca, Mg) tend to increase with CEC. Expressing the content of each cation as a % of the total cations (following Wacquant) gave better relationships. In general, % K decreased with CEC while % Ca increased with CEC, and % Na and % Mg were little affected, but there were still many exceptions to this rule. Variations in CEC due to external growth conditions did not seem to be of primary importance in affecting the change in % element with CEC.

The source of plant CEC is the carboxyl groups in plant uronic acids. The uronic acid contents, obtained by a decarboxylation method, were consistently about double the corresponding CEC values obtained by titration. An isotopic exchange method using ^{45}Ca, could achieve, by choice of experimental conditions, CEC values almost double the titration value, thus closely agreeing with the uronic acid content, but rather poorer relationships were found using these higher CEC values than the original titration values.

Since the movement in calcium has been postulated to be from exchange site to exchange site in contrast to other cations, consideration of CEC of plant tissues other than roots might be important in the relationship of CEC to mineral composition. The data were then analysed in terms of the ratio of the CEC values in the leaves compared to the roots. Genera, species or varieties could then be subdivided covering the same range of CECs, but grouped according to the ratio CEC_{Leaf}/CEC_{Root}. For instance, about 100 species of the genus *Allium* gave roughly equal groups in which CEC_L/CEC_R was low, moderate or high, in this case <1, $\simeq 1$, >1. For these three groups, % K was found either to increase with CEC_{Root}, to show no relationship, or to decrease with CEC_{Root}, respectively. Varieties of the annual aster species *Callistephus* showed a much narrower range of CEC than for differences between species, as with Allium, however a similar pattern of increase and decrease in % K (and the reverse for % Ca) with CEC_{Root} for different CEC_L/CEC_R groups was found, although here the ratios were all >1. Pea varieties were separated into 4 groups according to CEC_L/CEC_R; here the ratio was always <1 and as it increased, the relationship between % element *vs* CEC became more significant for all four major cations. Thus while separating data on the basis of this ratio is somewhat crude and arbitrary, it improved many of the tests of CEC against % ele-

ment. In many tests carried out formerly, relationships between CEC_{Root} and % element of total cations had been obscured by differing patterns being superimposed on each other, which were then separated by the groupings according to the ratio of CEC_{Leaf} to CEC_{Root}.

Rather than utilise CEC_L/CEC_R ratios by chance, they could to some extent be predetermined by using grafted material, when the CEC of root or top can be kept constant or varied. Grafted plum and apple trees show an improved relationship of CEC to % element for plants having similar ratios. Grafted tomato plants were produced in a water culture experiment with CEC_L/CEC_R ratios from 0·5-1·0. Subdivision into three groups again showed CEC *vs* % element giving a different slope of line (positive, then negative) at low and high ratios, but with no significant relationship at intermediate ratios.

Plant CEC is generally characteristic of a species, with only minor variations, but provenances of conifers and of birch derived from a wide range of latitudes showed a small but consistent change in CEC with latitude of origin, when grown together at one site. Changes in % element were found to correlate with CEC and consequently with latitude of origin. There are indications that published values of total nuclear DNA of species of *Allium, Lathyrus* and *Vicia* are related to the CEC of the species, and so may be involved in the distribution of cations.

It is generally held that calcium moves through plants by apoplastic pathways, i.e. through cell walls, which are the location of fixed carboxyl groups that can exchange calcium, while the movement of potassium is symplastic, i.e. through the cell interiors. The evidence given here shows that CEC within all parts of the plant plays a role in the movement of cations, and in particular affects the relative distribution of monovalent and divalent cations.

As well as the application of CEC in plant physiological studies on the translocation of cations, knowledge of the factors relating to the relative distribution of K and Ca in plants has importance in other fields. There are many calcium related disorders of plants and plant breeding programmes are directed to finding appropriate varieties. The ecological distribution of vegetation is also a subject in which a study of CEC could have wide application. A number of papers on this work are in preparation. 606, 613

Potato Composition. Preliminary work has been carried out on nutrient changes in the potato crop during the growing season. Successive pairs of leaves from single stems taken from plants having five stems were composited and analyzed. The concentration of most nutrients generally increased up the stem, apart from K and Na which were highest in the older (senescing) leaves. The choice of a particular leaf as a reference tissue varied with element and stage of growth, but as the composition did not alter significantly within the three pairs of leaves on the central part of the stem, any pair in that group would serve. However, estimation of the nutrient concentration of the whole plant (including stem) from analysis of leaf pairs

presents a much narrower choice. For samples taken in June-July leaf pairs 8/9 and 10/11 would give a reasonably accurate picture of nutrient concentrations in the whole plant at these times. Once the crop starts to mature the changes in the elemental content of tissues becomes less ordered so that for the assessment of the concentration of each element on a whole plant basis, a different leaf pair would be required. Clearly by this stage the idea of a reference tissue is no longer tenable. 606

Crop Composition: service facilities. Plant analyses of various kinds have been carried out for some years on behalf of the Scottish Crop Research Institute, in raspberry leaves, and potato leaves and tubers. Work on solute and osmotic potentials of tubers stored at different temperature has called for additional development work before analysing the constituents concerned. 606

Soil Physics

Publications on the prediction of bare soil temperatures from meteorological data, described in previous Reports, have now appeared in print[6, 7, 8]. The work on the variability of moisture release characteristics and pore space relationships both within and between soil series has also been published[9].

Soil Water Use by Spring Barley. Soil water contents to a depth of 90 cm were monitored during the course of the growing season, from 11.5.82 to 6.8.82, in a crop of spring-sown barley, using the neutron probe soil moisture meter. Rainfall during this period was small (6·0 cm), and many crops on shallow soils exhibited moisture stress, although this was not obvious in the experimental crop. Strong drying of the plough layer and the immediate subsoil to a depth of 30 cm was evident, but there was also considerable moisture depletion at 50 cm, and a little even as deep as 90 cm during July. Core sampling of the compacted subsoils under the nearby crop revealed that there were no roots present at 50 cm depth, only a few at 40 cm, but abundant roots at 30 cm. It therefore appears possible that the strong moisture potential gradients between the moist deeper subsoil and the drier layers above may have produced unsaturated hydraulic flow of sufficient extent to deplete the subsoil layers of water that had become available to the crop. Total water use during the period was 23·6 cm, close to the meteorological office estimate for potential evapotranspiration in the Aberdeen area. The water use efficiency of the crop was 191·3 kg/ha grain per cm of water, for a total yield of 4.51 tonnes/ha. 612

Soil Chemistry

Potassium. The comparison of electro-ultrafiltration (EUF) with physico-chemical parameters and conventional test methods for soil K, described in last year's report, has now been published[10].

Sulphur. A paper summarizing work in recent years has been presented at an international conference[11]. Work has continued with soils containing low amounts of phosphate-extractable sulphate, from several different Soil Associations, to evaluate critical plant S composition values for forage

crops. Current results from pot trials confirm those already found, namely that SO_4^{2-} – S is a better indicator of S deficiency than total sulphur or N:S ratio. From the work completed so far, it appears that adequate S is present when SO_4^{2-} – S values are 400-500 mg/kg, or when SO_4^{2-} – S is about 30% of the total plant S. These limits also apply to plant material from field trials.

Work has also been carried out to assess the effect of low S on the total N and NO_3^-N content of plants, as well as the amino acid and protein quality.

When extractable soil sulphate is low, mineralisation of organic S becomes an important component of the S supply to crops. A series of pot experiments has been set up with soils with variable amounts of organic matter, to measure the rate of mineralisation of organic S. Inputs from rain were eliminated, and radioactive ^{35}S was used as a tracer to help construct a sulphur balance. The indicator crops were oats in 1981 and ryegrass in 1982. The yield, response to added S, and S-uptake will be compared with several soil S measurements. Organic compounds in soils are being characterised in the laboratory by extracting them in acetylacetone with ultrasonic treatment; between 60% and 90% of the total S has been extracted in this way. The products are separated on a Sephadex column, freeze-dried and analysed. Some of these products will be used in laboratory mineralisation experiments.

When sulphur deficiency is observed in a crop it is too late to add sulphur to the soil. The use of a foliar spray for sulphate is, therefore, being examined in pot experiments with cereals and grass crops at different stages of growth. This appears to be an effective technique, although yields obtained with foliar sprays are only about three-quarters of those obtained with S applied to the soil at sowing time. 601

Soil Acidity. The Department has been involved in the soil aspects of the acid rain problem, and invited review papers have been presented to two international conferences[12, 13]. Publications on the dissociation of soluble polycarboxylic acids[14] from soils and their complexation with copper[15] have now appeared.

Aluminium solubility in some New Zealand variable-charge acid-clay soils has been determined to help resolve the anomaly of an apparent decrease in cation exchange capacity (CEC) with increasing pH of the extractant. The surface layers of the profile gave a lower CEC by the standard 1·0M ammonium acetate (pH 7·0) method than from salt-extractable cations at the natural pH of the soils (3·0 to 4·5), the opposite of what was expected. Leaching of 1·0 g samples of soil with unbuffered chlorides of K^+, NH_4^+, Mg^{2+} and Ba^{2+} showed that the relative effectiveness of these salts in displacing Al from the surface horizons was different from that of subsoil horizons, Fig. 7.2, and that this was related to differences in clay mineralogy of the horizons. In the surface samples showing anomalous behaviour, the dioctahedral interstratified illite/vermiculite collapsed to 10Å spacing on saturation with NH_4^+ or K^+, so restricting the exchange of Al

and giving low CEC values. This collapse did not occur with Mg^{2+} or Ba^{2+}, so that more Al was free to exchange. None of these salts caused the minerals in the subsoil samples to collapse. The differences between the clay minerals in the two horizons may simply be related to the amount of interlayer Al present, but further characterization is taking place. This work was done in cooperation with the Department of Mineral Soils.

604, 104

Following earlier pot work on the critical soil pH for spring barley (Report No. 50, 1979-80), the changes in mineral composition parameters of barley grown on two acid soils at a range of pH values were examined. Increases in yield and other growth and composition data were related to

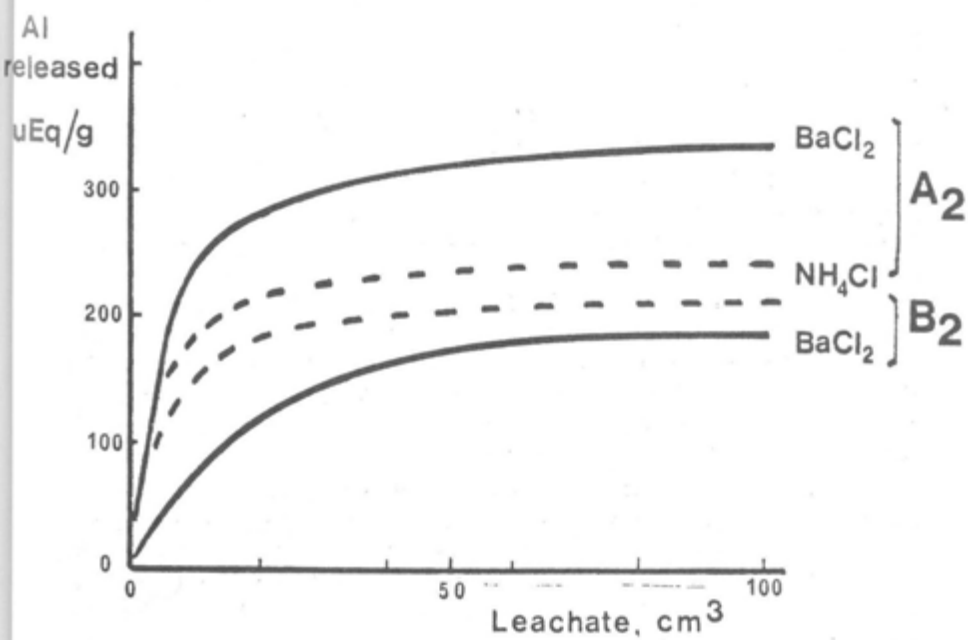

Fig. 7.2.
Neutral salt extraction of aluminium from soil of different horizons of Hallam profile.

soil pH, soil CEC and to soluble and exchangeable Ca and Al levels. The changes in the crop occurred at a lower pH where P had been added, but the crop composition details added little more to the information already gained from the simple yield data[16]. 606

Work on the contrasting growth and composition of an old acid-tolerant barley variety (Scotch Bere) and a modern variety (Golden Promise) when grown in limed acid soil with either NO_3^- or NH_4^+ as the nitrogen source, is being prepared for publication. The varieties differ also in their ability to offset the soil acidification produced by using ammonium sulphate fertiliser, due to their differences in cation and anion uptake which results in net excretion of hydrogen or hydroxyl ions. 606

Molybdenum. An investigation has continued on the effects of pH, soil organic matter and soil phosphate level on molybdenum solubility, following the publication of the methods used for molybdenum determination[17]. Extraction with 1·0M ammonium acetate solution failed to highlight any significant relationship between extracted molybdate and soil pH, over the fairly narrow range from pH 3·6 to 5·6. Accordingly, sub-samples of selected soils were equilibrated at a range of pH values from 3·7 to 8·0 for three days, extracted with 0·02M KNO_3 solution and molybdate was determined in the extract by differential pulse polarography. The conductivity of each extract was measured to evaluate the ionic strength, so that the molybdate activity (pMo) could be plotted as a function of pH. Preliminary results indicate that there is generally a positive linear relationship between pMo and pH. More molybdenum is desorbed from soils that have received a large phosphate amendment but no lime, and less, but similar, amounts from soils receiving no lime and no P, or both lime and P. In the presence of lime but without added P, the pMo - pH relationship is non-linear, showing a pronounced dip between pH 5·2 and 6·8. 614

Electrochemical Techniques. The unique behaviour of the static mercury drop electrode, has been exploited to provide a method of analysis for molybdenum by differential pulse polarography in the presence of a 4000-fold excess of Fe^{3+}, which can occur in soil digests. Normally this would entail the prior separation of the molybdenum, or the removal of the iron, but neither of these operations is now necessary. This work has been published[18]. Preliminary work on the fabrication and use of microfaradaic electrodes has shown that these electrodes, made from 8-10μ diameter carbon fibres, exhibit unusual electrochemical properties and show promise for *in situ* determination of trace elements in soils.

A flow injection analysis system for soil pH measurements is under construction. Significant problems arising from static electrical interference have been overcome by using guard electrodes before and after the peristaltic pump. Minimum sample dispersion has been achieved by using large sample volumes (100 μl), minimal detector volume (<5 μl) and a low flow rate. 614

Phosphate. A summary of work on the effect of differing soil buffer capacities for phosphate on P uptake by ryegrass, described in Report No. 49 (1978-79) has appeared[19]. More extensive work covering a wider range of Scottish soil series, using both oats and ryegrass in pots as test crops, has begun. 601

Selenium. Pot experiments on the effects of selenite added to nine representative Scottish soils have now been concluded. Measurements were also made in the laboratory of the soil selenite adsorption properties. The solution selenite concentration, when a total of 1 μg/g of selenite was added to the soil, was used as a measure of selenium availability. This correlated well with uptake by ryegrass of the added selenite ($r=0{\cdot}93$, $P<0{\cdot}001$).

The residual effects of the selenium additions in subsequent years were small ($<10\%$ of the uptake in the year of addition). Moderate soil selenium

amendments would therefore have to be made on an annual basis to maintain adequate selenium for herbage. Plant selenium concentration also decreases with growth rate so that selenium deficient herbage is more likely to be produced under conditions of vigorous plant growth. 609, 614

Manganese. Pot and laboratory experiments complementary to the field trials mentioned earlier have investigated the effectiveness of soil, seed and foliar spray amendments with manganese as $MnSO_4$. Barley seeds were loaded with 2·5, 5 and 10 mg/g of Mn labelled with ^{54}Mn. Plant contents at the 3-leaf stage were 46, 50 and 56 μg/g Mn compared to 37 μg/g in the control. Radiochemical measurements showed that 16, 17 and 24 μg/g of the plant Mn was derived from the seed treatments. At ear emergence, both Mn contents and radiochemical measurements indicated no difference between the treatments and the control, so that the seed treatment seems to be effective only in early growth, but this may be when barley is most susceptible to Mn deficiency. The soil used did not appear to be particularly Mn deficient because additions of 15 and 30 μg/g Mn to the soil before potting gave only small non-significant increases in plant Mn content. Radiochemical measurements showed that Mn added as a $MnSO_4$ foliar spray at the 5-6 leaf stage had been translocated to more recent growth by the ear emergence stage. No manganese deficiency symptoms were observed in this experiment although the soil used had been shown to produce a marginal manganese deficiency under field conditions. 609, 614

Development and Advisory Work

Soil Test Methods. Discussions have been held with soil chemists in the East of Scotland College of Agriculture and the West of Scotland Agricultural College on uniform methods of analysing advisory soil samples and reporting the results. Amounts of P extracted from soils by a number of methods, including 2·5% acetic acid (pH 2·6), Morgan's reagent (ammonium acetate + acetic acid, pH 4·8) sodium bicarbonate, anion exchange resin, and ammonium lactate + acetic acid (pH 3·8) have been determined and the correlations have been calculated between them and the response to applied P with swedes and potatoes in field experiments and with oats in pots. As noted previously (Ann Rept. No. 48, 1977-78) anion exchange resin gave the highest correlations for the combined results for nine soil series in the pots and five soil series in the field experiments. Soil P determinations by ammonium lactate + acetic acid have given at least as good correlations as by acetic acid and Morgan's reagent, the methods currently used for analysing advisory samples.

In field experiments with swedes, and to a smaller extent in pot experiments with oats, the correlation coefficients between the responses to applied P and soil P values are substantially higher for individual soil series than for the combined group of all soil series. For instance, with swedes, the best correlation coefficients (r) for individual soil series with anion exchange resin ranged from 0·72 to 0·89 while that for the combined group was 0·67. The corresponding coefficients for the acetic acid method were 0·63 to 0·82, and for the lactate method 0·64 to 0·83, the combined groups giving

0·60 and 0·58 for the two methods, respectively. The classification of the P status of advisory soil samples could, therefore, be appreciably improved by having different limiting values for individual soil series or groups of soil series.

It has been agreed that the lactate method should be used at all three centres for analysing advisory soil samples. Work is in progress to correlate the P, K, Ca, and Mg values given by this method with those obtained by the acetic acid and Morgan's methods, currently used, so that critical limiting values can be established for the five agreed classification categories of very low, low, moderate, high and excessively high. These five categories correspond to ADAS indices of 0, 1, 2, 3 to 7 and 8 to 9 respectively. Development of the anion exchange resin method for routine soil P determinations is continuing. 608, 5703

A uniform system for methods of determining and classifying the trace element status of soils, using a similar five category system to cover the range from deficient to potentially toxic, is also under discussion. 609

Advisory Analyses. Just over 7,400 soil samples, including 125 from horticultural areas, were submitted by the North of Scotland College of Agriculture for assessments of lime status and requirement and of phosphorus, potassium and magnesium status. Both field information and the analytical results from these samples are stored in a data bank for future information. The results, mostly from arable land growing at least one crop of barley in the rotation, are beginning to show a decrease in lime status due to the marked reduction in the amounts of lime applied during the previous five years. The proportion of samples classified low in lime and requiring over 5 t/ha calcium carbonate has increased from 25 to 30 per cent, while the proportion requiring maintenance applications of 2·5 to 5 t/ha calcium carbonate has remained at about 55 per cent. The proportion of the samples with a high lime status and not requiring lime at present has decreased from about 20 to 15 per cent. It seems that adequate lime is not generally being applied, and this might lead to reduced yields of barley if the trend continues. 608, 610, 5206

Field experiments over many years have shown that, provided lime status is satisfactory, the highest yields are normally produced on soils with phosphorus and potassium status in the moderate or high categories. Over the past 10 years there has been no improvement in the phosphorus and potassium status of advisory soil samples. This year the proportion of samples with a high phosphorus status has fallen from about 27 to 18 per cent, the proportion with a moderate status has remained constant at about 52 per cent, while the low category has increased from about 20 to 30 per cent. This decrease in the phosphorus status of soils is doubtless associated with the lower amounts of phosphate and higher amounts of nitrogen being applied to British soils. There has also been a marked increase from about 5 to nearly 20 per cent in samples with a low potassium status, while the percentages with a moderate or high status have decreased by about 8 per cent to 55 and 25 per cent, respectively. Some of this decrease in potassium

status may be associated with cutting herbage for conservation and with the increase in growing cereals, but it is a matter for conjecture whether excreta from livestock are being efficiently conserved and utilized. 608, 610, 5206

In collaboration with the Department of Spectrochemistry, trace elements were determined in 400 of the advisory soil samples and in 35 plant samples. The determination of manganese in field moist soil by equilibration with 0·01M $CaCl_2$ solution is very useful in helping to diagnose manganese deficiency in crops. Several shell sands and calcareous rocks have been analysed to estimate their value as liming materials. A few samples of sewage sludge from various towns in Grampian Region have also been analysed for plant nutrients and potentially toxic elements. Nearly 190 soil samples, mainly from forest nurseries, have been analysed to assess their lime, phosphorus, potassium and magnesium status in collaboration with the Department of Peat and Forest Soils. Many written and verbal requests about soil, crop and related animal problems have been dealt with, and a few talks given to farming groups. 117, 608, 609, 610, 5205, 5206

Radioactivity

Purchase of a Packard Auto-Gamma Spectrometer has greatly facilitated γ-counting techniques for isotopes such as ^{54}Mn, ^{58}Co, ^{59}Fe, ^{65}Zn, ^{75}Se and ^{133}Ba used as tracers in Plant Physiology and Soil Organic Chemistry as well as within Soil Fertility. Beta emitting isotopic tracers are also used extensively and measured by liquid scintillation counting. Uptake studies by plants of ^{35}S and ^{32}P continued in studies of fertility. The use of ^{14}C as a tracer continues to be the largest work load of the radioactive laboratory, mainly in soil and plant polysaccharide studies in collaboration with the Department of Soil Organic Chemistry. 613, 5613

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8. STATISTICS

R. H. E. INKSON

The work of the Department is devoted to providing specialized advice and services to the rest of the Institute. The close collaboration starts at the planning stage of experiments with the choice of the appropriate design and continuues with advice on recording results. The consequent method of statistical analysis is determined at this stage. In addition to the selection and application of a range of methods of statistical analysis, the Department also provides specialized services in all aspects of computing from data entry, programming and operation to database management, and runs courses of instruction in the use of computer terminals and in programming.

Members of staff attended meetings of the Biometrics Society, the Royal Statistical Society and the Forest Modelling Discussion Group, computer exhibitions, workshops and conferences, and training courses on computer use and programming.

Computing

The Department is responsible for the management and development of the Institute's central computing system with its network of terminals, on-line instruments and peripheral equipment. An asynchronous line multiplexor has been added to the system to allow the connection of five new terminals. The Calcomp drum plotter has been replaced by a very much faster Benson 1222 plotter. Three diskette drives now reduce queueing for the use of this facility. A Diablo daisywheel printer gives a superior quality of printed output. There are now 24 terminals and items of equipment interfaced to the Data General Eclipse in addition to the central printing and tape, disk and diskette storage facilities. 703

New equipment interfaced to the computer has required the writing of software to allow the necessary communications, particularly for the Diablo printer and the Benson plotter. Routines written for the latter include a graph drawing routine, GRAF, and a new general plotting program, DEALBH, which replaces CLBNP. This program has all the features of the old one plus some new ones and a much more convenient organisation of input. The Benson software allows a more presentable graph to be produced for the same or less programming effort. Another new program, DEISEAL, prepares the input files for DEALBH. It allows data in either of the two most commonly used standard formats to be combined with a separate instruction file, suitable graph limits and scales calculated,

groups for different plot symbols selected and the output provided as a file which can be used directly as input to DEALBH for plotting. A considerable effort was also devoted to converting users' programs and to helping users to convert their plotting programs. 115, 203, 5703, 703

The program package, GLIM, for the fitting of generalised linear models to data is now in use on the Data General Eclipse. A random sort program has been written to extend the random number generation facilities of GLIM in two ways. The first removes repeat occurrences of the same number and adds 1 to produce random permutations of the numbers 1 to n, and the second produces pairs of random co-ordinates within specified limits without duplication. The data entry and verification system has been further developed to facilitate the later addition of data to files previously verified. More time is now required by system work for the general revision and updating of the operating system, for security back-up and archiving, and for responding to users' needs in plotting and in magnetic tape and diskette storage and retrieval. 701, 703

One further statistical analysis program has been converted from the IBM 1130 version to run on the Eclipse. It allows for a repeated control treatment in each block of randomized block experiments. Two new programs have been produced as modifications of old ones to allow new options. Where, for example, two crop varieties are grown on different replicates (as main plots) of a central composite design, the new program includes tests of the differences between corresponding coefficients in the two quadratic equations. The factoral analysis of variance program for up to five factors can have more plots and fewer orthogonal component options in the analysis of variance or vice versa. Some of the general statistical subroutines have been rewritten from the initial Eclipse version to improve efficiency. They are being linked to the mainline programs as suitable opportunities arise. 701, 703

Mineral Soils. Data from the physical, chemical and mineralogical analysis of over 300 profiles are now included in the " Mineral Soils " database. COR2, a large program for quantitative electron probe microanalysis, has been successfully modified to run on the Eclipse rather than on a larger computer. Its space requirement has been decreased from 72 Kbytes to 28 Kbytes by using overlays, reducing the size of common blocks and limiting the number of elements to 40 instead of 100. It can calculate either the theoretical relative intensities for specimens of known composition or the composition of analysed specimens. 101, 107, 5703, 703

Peat and Forest Soils. A service has been provided in processing LANDSAT MSS data from magnetic tapes. An example of the use of our programs for the selection of classifications and other processing to generate maps is included in a joint publication[1]. 119, 5703, 703

Spectrochemistry. 273 data sets stored in dumped binary format on about 125,000 IBM punched cards are now accessible on the Data General Eclipse. The card reading facilities and the Honeywell computer at the University of Aberdeen were used to transfer the data from the cards to

magnetic tape in 7 long computer runs. Programs were written to decode the dumped binary information and reconstitute the original data sets which are now backed up on a single 2400 foot magnetic tape. The service continues for data input from punched paper tape, for plotting spectra and for graphical output. 201, 203, 205, 206, 5703, 703

Soil Organic Chemistry. Programs have been written to select, extract and plot data from files containing a range of chemical properties of the horizons in 173 soil profiles in a podzol chronosequence study. 304, 5703, 703

Soil Fertility. The Commodore PET used for data processing in the Department of Soil Fertility has now been interfaced to the Eclipse via the new line driver unit to provide direct access to the Eclipse facilities for the soil advisory service. 608, 5703

Soil Survey. For the Soil Inventory of Scotland taken at 5km intersection points, 671 profile description records (about 20% of the country) are now held in the database. The areas completed are the undifferentiated peat profiles in Uist, Lewis and Harris, the north-west around Ullapool, the south-west around Newton Stewart and the area in central Scotland between the Trossachs and the Grampians. The following procedures are being adopted to transform the data into the information required:

a) efficient coding of data using the INFOS file management system,
b) retrieval of specific data using INFOS Query/Report Writer,
c) more complex retrievals using RATFOR, a structured preprocessor for FORTRAN programs,
d) ordering of selected data using SORT/MERGE or in-core sorting,
e) statistical analysis using GLIM or other programs and
f) neat reporting using the text-formatting program, REFORMAT.

A joint account[2] of the use of the recording form and of some of the processing programs has been accepted for publication. 5703, 703, 801

In an investigation on behalf of the National Coal Board at Keirsbeath near Cowdenbeath the data from 173 profiles were entered, verified and stored on disk. Statistical analyses were performed on extracted data files to establish the depths, texture, drainage and stoniness of various horizons[3]. Data entry and sort programs have been converted to run on the Eclipse to extract and summarise soil and site data for profiles on soil complexes at Ardnamurchan, Morven and the Isle of Mull. Data entry, processing and retrieval work has continued on vegetation surveys. 5701, 5703, 703, 801, 802

Statistical Advisory and Collaborative Work

Peat and Forest Soils. Rainfall data from the last two Sitka spruce experiments, in the series of six with central composite designs, have been processed as described on page 94 of Annual Report No. 51, 1980-81. An investigation of seasonal patterns of growth for some of the variables has begun. Needle weights and elements in various tree parts, as part of whole tree sampling of Sitka spruce, have been processed and a joint account of work[4] on the nitrogen content of pine needles has been published. A

regular service is provided to process the results of chemical analyses of tree and rainfall samples, and to build up data files. Sets of random co-ordinates for use in locating new rainfall collectors at Balquidder have been produced by GLIM and the new RANDOM.SORT program. Some work on modelling nutrient cycles has been done on nutrients in birch trees and those released from litter. 115, 5701, 5703, 703

The Glentanar rainfall project has provided further data for processing and analysis. An increase in the number of sampling points meant that computer programs had to be amended. The opportunity was also taken to include additional features in the basic programs to reduce the number of runs required to provide all the information requested. Earlier data sets were then re-run with the new programs to obtain all the results to date in the same standard format. Soil water has been sampled at Fetteresso forest since June, 1979, and the initial stages of the processing of over two years of data have been completed. This was conversion of volumes to mm rain and mg/l to milli-equivalents of elements, with means and coefficients of variation obtained for matching catchers. New programs were written for this project based on those used for the Glentanar rainfall data.

115, 5701, 5703, 703

Soil Organic Chemistry. Statistical analyses have been done on data (mainly content of copper and other elements) from two experiments continued for three years on the effects of peat amendment on Cu toxicity and ryegrass. A joint account of work[5] on the amino acid composition of oat plants from a 2x2x4 factorial experiment has been published.

307, 5701, 5903

Plant Physiology. Factorial and randomized block designs have featured in studies of the growth rate and chemical composition of lemna fronds, often with selenium as a factor. Factorial designs have been used in experiments with Brussels sprouts, and the angular transformation was applied to the percentages affected by internal browning. The angular transformation was also used in assessments of damage by cavity spot of carrots in a factorial experiment and a joint account of this work[6] has been published. Both factorial and randomized block designs were used in tomato experiments testing the effects of moisture regime, source of nitrogen supply and truss size. Joint accounts of this work[7, 8] have been published.

401, 402, 5701, 5703

Microbiology. Dilution series data have been processed and interpreted for a number of experiments and tests of signficance of the differences between treatments made on a logarithmic scale. Further counts of aerobes and anaerobes in peat samples have been analysed by the revised factorial program using the logarithmic transformation. Work has also continued on examining the linear regression relationships between rate of heat output, biomass and respiration for groups of soil samples. Analyses of variance and tests of the significance of differences between treatments have been made for a number of experiments measuring yield, total N and % ^{15}N in grain, shoots and roots of cereal plants.

503, 510, 512, 513, 514, 5701, 5703

Soil Fertility. The field experiment program of new and continuing experiments includes a range of designs from randomized blocks to central composite designs and lattice squares.

5701, 601, 603, 607, 608, 609, 612, 701

The investigation of the relationship of crop response to added fertilizer with various laboratory measurements of soil phosphorus has continued with the addition of new models. Regression relationships of P uptake and exchangeable P in soil with other soil properties have been examined. The study of the pattern of plant growth and development of barley, oat and swede crops has continued with the application of analysis of variance and regression methods to physical and chemical properties and growth rates of plants. Exponential curves have been iteratively fitted to yield and nitrogen fertilizer data expressed as shortfalls from estimated maxima for a group of experiments conducted over a number of years. The results of this curve-fitting study are being prepared for publication.

5701, 5703, 601, 605, 607, 608, 701

Correlation analysis has continued relating chemical properties of many plant species to each other and to site properties. The results of two factorial experiments with sulphur, and nitrogen and potassium as factors have been analysed and a joint account of the work[9] accepted for publication. A joint account of work[10] on the regression relationships between soil porosity and water tension has been published. 5701, 5703, 601, 612, 613

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9. SOIL SURVEY

R GRANT

The Department has suffered a serious loss in the past year through the earlier than anticipated retirement of four senior members of staff, Messrs D. Laing, J. W. Muir, E. L. Birse and J. C. C. Romans. These four have contributed a total of 130 years of service to the Soil Survey and the Institute; their company and accumulated knowledge, often specialised, will be missed and not replaced easily.

The 1:250 000 mapping project, which has been the Survey's main preoccupation since 1979, is nearing completion, as reported below, and a start has been made towards completing the systematic survey work held in abeyance.

The acceptance by the Department of Agriculture and Fisheries for Scotland of the revised Land Capability Classification for Agriculture[1] has led to a considerable strengthening of collaboration during the past year. Projects are in hand to supply figures for the Scottish Development Department on the amount of agricultural land in various classes, both nationally and by regions, coupled with some data on current land use.

An exhibition displaying some of the work and productions of the Soil Survey was presented at the Royal Highland Show at Ingliston, Edinburgh.

Members of staff attended meetings of the British Society of Soil Science in London and Aberystwyth and of the Hill Land Use and Ecology Discussion Group in Skye.

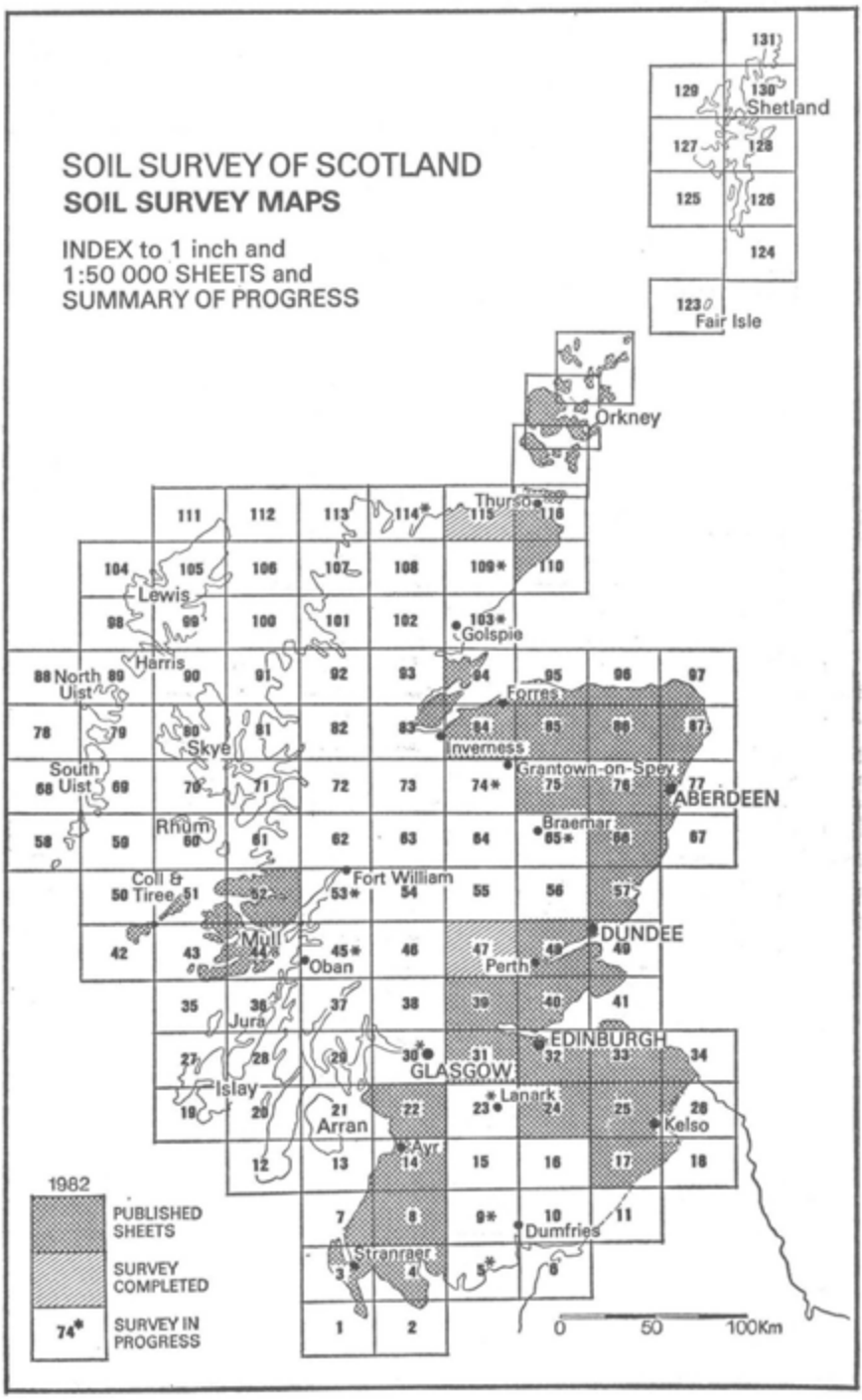
Mr J. S. Bibby accepted an invitation to become a Visiting Professor in Soil Survey and Land Use at Strathclyde University.

The Soil Survey has been represented on the DAFS Working Party on Hill Land Classification, the ARC Soil Survey Research Advisory Committee, the Ordnance Survey/Public Agencies' Consultative Committee and the Scottish Agricultural Field Drainage Group. 801, 802, 804

1:250 000 Survey

All seven soil maps have now been printed by Ordnance Survey and the stocks delivered to the Institute. Meetings of the MISR-DAFS-COSAC-NFU Consultative Committees on land capability assessment have been held in Ayr, Edinburgh, Perth and Inverness at which final drafts of the land capability for agriculture maps at 1:250 000 were discussed. Agreement was reached in each case, and corrected colour proofs of all seven maps have now been submitted to the O.S. for printing.

Progress has been made with the accompanying descriptive handbooks, four of which are at the final draft or printing stage. 801


SOIL SURVEY OF SCOTLAND
SOIL SURVEY MAPS
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ABERDEEN
Rhum
Braemar
Coll & Tiree
Fort William
Mull
DUNDEE
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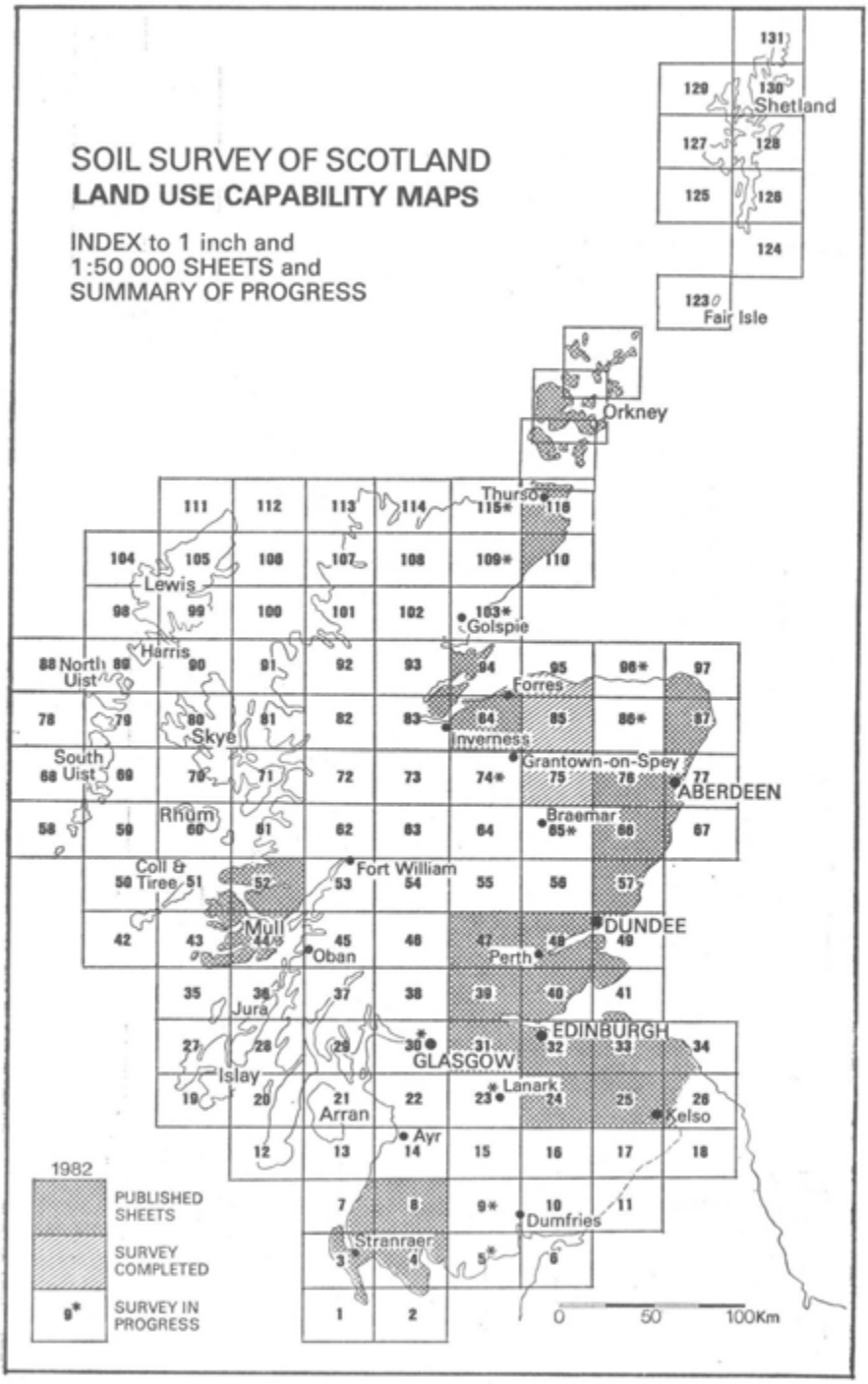
SOIL SURVEY OF SCOTLAND
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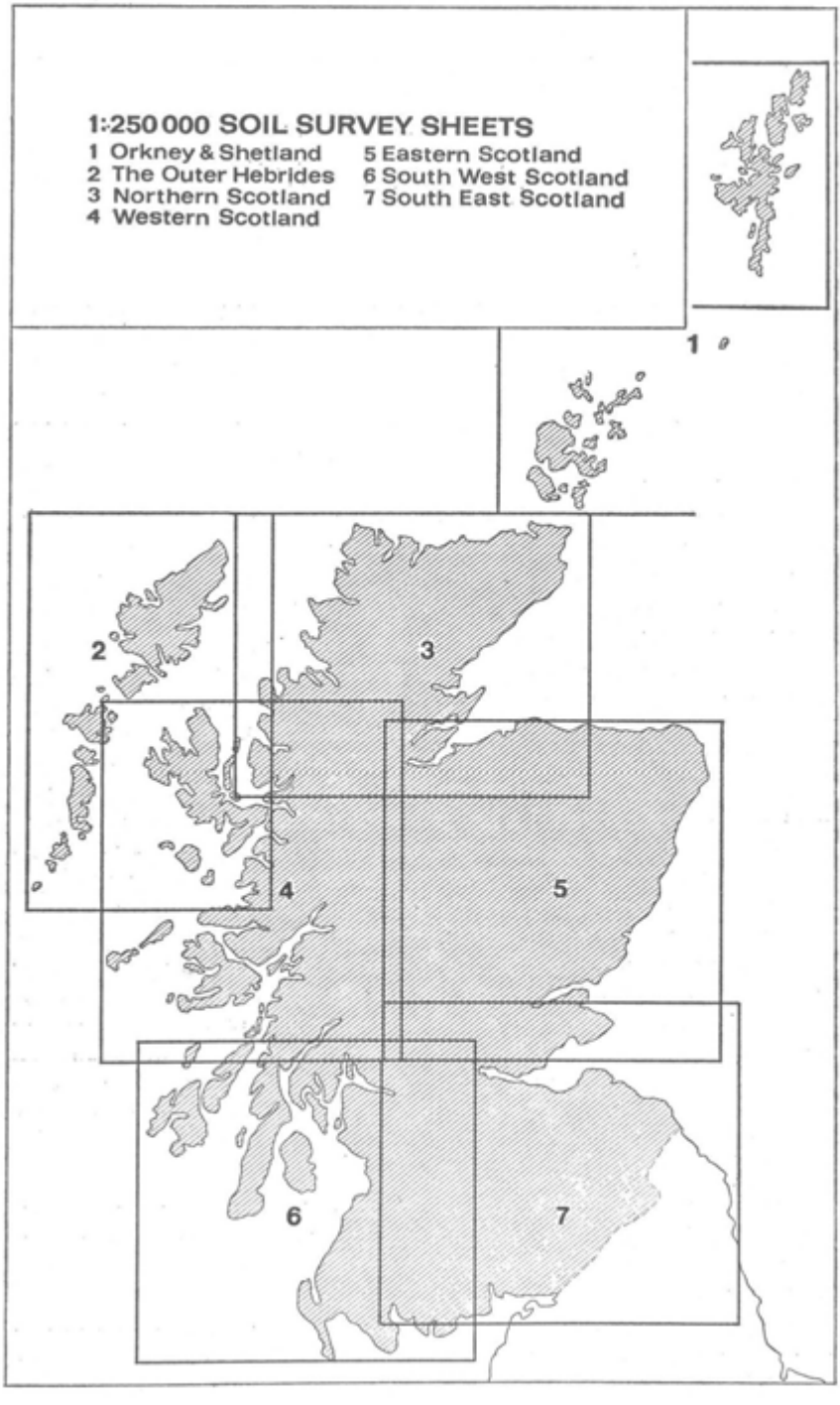
1:250 000 SOIL SURVEY SHEETS
1 Orkney & Shetland
2 The Outer Hebrides
3 Northern Scotland
4 Western Scotland
5 Eastern Scotland
6 South West Scotland
7 South East Scotland
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National Soils Inventory

Soil profile descriptions have been collected from a further 470 5 km National Grid intersect points, with samples from the 10 km intersects, bringing the total to 1255, approximately 700 of which have been entered in the Institute's soil data base. Full analytical results have been included for approximately 200 of these. A joint paper[2] on the use of the recording form and the processing form has been accepted for publication. 801

Sheet 23 (Hamilton)

The systematic 1:63360 soils and land capability for agriculture surveys of sheet 23 (Hamilton) resumed this year. Approximately 255 km^2 have been surveyed in three main areas (a) to the north and west of Strathaven and extending south-westwards along the valley of the Avon Water, (b) to the south of Strathaven, between Strathaven and Muirkirk and (c) around Coalburn and Douglas to the north of Douglas Water and to the west of the A74.

The undulating till-covered lowlands to the north and west of Strathaven are dominated by the soils of two principal soil associations, the Darleith and the Kilmarnock Associations, while in the valley of the Avon Water and its tributary, Glenavel Water, extensive fluvioglacial sand and gravel deposits of the Darvel Association were mapped.

The Darleith Association comprises soils developed on drifts derived from basic igneous rocks of Carboniferous age and is largely limited to the western edge of the mapped area. The association is dominated by imperfectly drained brown forest soils (Dunlop Series) developed on a brown sandy clay loam or clay loam till. Pockets of a poorly drained noncalcareous gley soil (Amlaird Series) and freely drained Darleith Series (brown forest soils) occur locally. Eastwards, towards Strathaven, an increasing influence of Carboniferous rocks on the parent material becomes apparent and a mixed drift of igneous rocks and sediments of Carboniferous age (Kilmarnock Association) begins to dominate the landscape. The principal soil is the imperfectly drained brown forest soil of the Kilmarnock Series developed on a brown or reddish brown sandy clay loam or clay loam till. An imperfectly drained brown forest soil developed on till with partially water-sorted surface layers (Brownrigg Series) occurs locally and generally in conjunction with sand and gravel deposits. The dominant soil of the Darvel Association (fluvioglacial sands and gravels derived mainly from rocks of Carboniferous age) is the freely drained Darvel Series — a brown forest soil.

Hill peat is extensively developed along the western border to the north-west of Strathaven and a number of basin and valley peat deposits have been mapped throughout the area, the most extensive of these deposits being Cladance Moss and Mossmulloch.

The area to the south of Strathaven, between there and Muirkirk, is principally hill ground and is dominated by hill peat. Areas of both thin peat (thickness of 50 to 100 cm) and deep peat (thickness in excess of

100 cm) have been mapped. In rare instances only does the peat thickness exceed 150 cm.

A number of soil parent materials other than peat have been met — the array of parent materials being a reflection of the complex geology and glacial history of the area. Soils of the Reppoch/Ettrick (drifts derived from Downtonian sandstones and shales), Giffnock and Rowanhill (drifts derived from sediments of Carboniferous age) and Sorn (drifts derived from sediments of Old Red Sandstone and Carboniferous age) Associations were mapped. The soils are not extensive and are closely inter-related with the common characteristic of generally poor drainage, noncalcareous gleys and peaty gleys dominating. A small area of soils developed on drifts derived from felsite (the Knockskae Association) was mapped on Black Hill immediately north of Muirkirk and an area of fluvioglacial sands derived from Old Red Sandstone sediments (the Eckford Association) was mapped north of the farm of Burnfoot, some four kilometres north-west of Muirkirk.

The soils around Coalburn are developed largely on drifts derived from sediments of Carboniferous age (the Giffnock and Rowanhill Associations) and in many instances the parent material has been modified by water-working of the surface layers. The principal soils are the imperfectly drained brown forest soil (Kennet Series) and the poorly drained peaty gley soil (Glaisnock Series). Basin peats are mapped locally, an extensive deposit occurring immediately to the north-east of Coalburn. A large expanse of fluvioglacial sands and gravels of the Darvel Association occurs in the valley of the Poniel Water and similar deposits with alluvium occupy the valley of the Douglas Water. Extensive areas of disturbed ground associated with past coal-workings were mapped around Coalburn.

The principal area of arable agriculture encountered lies to the south-west of Strathaven along the valley of the Avon Water and grass for grazing and conservation is the main crop. Most of the land of the arable belt is considered as Class 4 — land that is suitable for enterprises based primarily on grassland with short arable breaks. Climate (exposure and an annual average rainfall generally in excess of 1200 mm) and the presence of slowly permeable sub-soils in those soils developed on till are the principal limitations on arable agriculture. The slowly permeable sub-soil is not a problem in the soils of the Darvel Association, but coarse texture, stoniness, the occasional cemented sub-surface horizon, pattern and slope can impose restrictions on land use.

Much of the hill ground to the south of Strathaven is considered as Class 6 land with some Class 5 where soils and climate permit reclamation.

801

Sheet 75 (Tomintoul)

Preliminary fieldwork has been completed for the production of a Land Capability for Agriculture map of Sheet 75 (Tomintoul) at 1:63 360. This area has been re-examined and interpreted applying the revised (1982) guidelines for Land Capability Classification for Agriculture[1], with all land being assigned to a class, a division and a limitation type.

As the area is predominantly upland, climatic restrictions operate widely and arable cultivation is largely confined to valleys and other low-lying situations, often on the more favourable parent materials such as drifts derived from slaty schists or basic igneous rocks. The best land, Class 3.2, occurs in the Logie-Coldstone basin on till derived from basic rocks. Class 4.1 land is found mainly below 300 m in Strathspey, Strathdon, Glenbuchat and lower Glenlivet where soil and slope are suitable. Most land suitable for arable cultivation has been classified as 4.2 with substantial areas in the aforementioned locations, as well as in the Tomintoul and Cabrach district, an upper altitudinal limit of 460 m being attained near Allangue. Although the most frequent limiting factor is climate, steep slopes on lower Glenbuchat and lower Strathdon downgrade land to 4.2, whereas in Strathspey this category is applied to low quality soils on gravel or poorly-drained till.

Land suitable for improved grassland, Class 5, extends up to the base of the subalpine soil zone in some areas. Class 5.1 is limited, occupying a few scattered patches. Both Classes 5.2 and 5.3 however are abundant, the former including extensive areas of humus-iron and peaty podzol, the latter often being applied to steep slopes (15 to 25°) on soils ranging from brown forest soil to peaty podzol. Some basin peats are classed as 5.3 Much Class 5 land is found on the hills in the Strathavon, Glenlivet and Strathdon areas.

Class 6 land, suitable only for rough grazing, is the most abundant in the area. It comprises large tracts of hagged blanket peat, for example to the north of the Cairngorms and on the Ladder Hills, subalpine soils, steep and very steep slopes, rocky and bouldery ground most frequently associated with areas of quartzite, granite and basic and ultrabasic igneous rock. Good quality grazings are largely confined to the steep slopes of Glen Avon where there are rich bent-fescue communities on soils developed on limestone. Moderate quality grazings (6.2), mainly of *Nardus* communities are widespread but mostly of limited extent, often occurring as prominent green flushed sites within the predominance of heather moor, for example on the slopes north of the summit of the Lecht road. However, vegetation communities of low grazing value (6.3), mainly boreal heather moor on podzolic soils and blanket bog on peat, dominate the hills and occupy over 90 per cent of Class 6 land.

Mountain summits with alpine soils and rankers and some scree-dominated slopes are assigned to Class 7; the Cairngorms in the south-west of the sheet form the most extensive area. 801

Special Surveys

At the request of DAFS, soil surveys were made of a number of proposed NCB open-cast coal extraction sites. Soil maps and reports are being submitted to assist the planning of the operations and the eventual restoration of the sites.

Ponesk, Muirkirk, Ayrshire. Four soil associations were identified (Giffnock, Rowanhill, Sorn and Darvel) with the poorly drained peaty gley

soil (Glaisnock series) of the Rowanhill Association dominating the landscape. The Glaisnock Series is developed on grey or dark grey clay loam till. The thickness of the peaty surface horizon rarely exceeds 40 cm.

Rough Hill, New Cumnock, Ayrshire. Most of the soils of this site, which occupies 316 ha, were mapped as poorly drained series of the Ettrick Association, developed on till from greywackes and shales of Silurian age, and underlain by Carboniferous strata. Smaller areas of deep, freely drained soils of the Darleith Association, developed on weathered dolerite, alluvium and peat were also mapped.

Keirsbeath, Fife. Approximately 172 ha were surveyed with 174 profiles being examined on a 100 m grid intersection plan. The information on both the site and soils at these points was recorded on specially designed computer-compatible recording cards and was subsequently transferred to the Institute computer. The data were statistically analysed. Colour graphic display of the data was achieved on the Tektronix 4027 terminal and a series of single factor maps, e.g. display of topsoil depths, display of topsoil textures, etc. was produced. All such information was submitted to DAFS along with a report on the general soil and land use capability characteristics of the study area.

Loch Lomond Nature Reserve. At the request of the Nature Conservancy Council, the soils of the Loch Lomond Nature Reserve were surveyed at a scale of 1 : 10 000 and a map prepared. Occupying approximately 5 km², the Reserve consists of two distinct areas: the flat alluvial haughlands associated with the mouth of the River Endrick and the islands of Inchcailloch, Creinsh, Torrinsh and Clairinsh. The soils of the former area are generally poorly drained, with a heavy texture and high groundwater table. Old river channels tend to be infilled with peat and extensive areas of peaty-alluvium were mapped. The soils on the islands are generally brown forest soils and brown rankers belonging to either the Stonehaven or Leslie Associations. The soils developed under the long-established woodlands are of scientific importance because they display the natural pedogenic cycle and trends in areas of relatively undisturbed vegetation. For this reason, several profiles have been sampled. The information will be incorporated in a report for inclusion in a book on the ecology of the Reserve.

Craig Odhar. The plant communities on Craig Odhar, near Blair Atholl, have been recorded and soil samples have been collected from the dominant soil types, which have been mapped as rendzinas and brown calcareous soils. This forms part of an endeavour to elucidate the relationship between the plant communities and soils developed on limestone rock. 801

Vegetation Surveys

The boundaries of the vegetation mapping units of the Gairloch area have been transferred from the aerial photographs to an Ordnance Survey base map of scale 1 : 10 000. The mapping was completed during May and June, 1982, and a number of unrecorded or under-recorded plant communities were sampled to complete the tables of the vegetation.

Bulletin No. 4, "Plant Communities of Scotland: a Preliminary Phytocoenonia,"[3] the paper entitled "The main types of woodland in North Scotland"[4] and a paper on the serpentine vegetation of Scotland[5] have been published.

A paper on the species-rich scrub of Orkney[6] has been accepted for publication by the Transactions of the Botanical Society of Edinburgh.

Tables of plant communities for a second part of the Phytocoenonia of Scotland have been prepared and the timothy hay meadows of the Carse of Stirling, the mountain bog vegetation on Moine Mor in the Cairngorm Mountains and the upland birchwoods of the Monadhliath Mountains were recorded for inclusion in this work.

Much of the year was spent in writing-up general descriptions of the vegetation for each region of the 1:250 000 upland survey for inclusion in the handbooks and in preparing a section on the classification and characteristics of the plant communities listed on the 1:250 000 soil map keys for the handbook on organisation and methods.

A start was made on the field work associated with the 1:50 000 soil survey of Sheet 23 (Lanark) in which the natural and semi-natural vegetation of that area was recorded by standard phytosociological methods.

Changes in the vegetation of the experimental heather regeneration plots in Glen Artney were monitored for the third consecutive year and a report on the results is to be prepared. The plant communities of a potential conservation site at Swinkie Muir near Kingsbarns were assessed for the Scottish Wildlife Trust.

A short field course on plant community recognition was held for DAFS Lands Branch officers to assist them in the classification of hill land and further joint trips were made to discuss the integrated use of hill areas.

A paper on vegetation surveying and mapping in Scotland[7] was presented at a seminar of the International Cartographic Association (Euro-Carto I) held in Oxford and has been accepted for publication in Cartographica. 802

Soil Micromorphology

During the current year, laboratory work has resulted in the preparation of 390 soil thin sections. Although the majority of these have been prepared in connection with Departmental micromorphological studies, both rock and soil materials have been sectioned for other departments, and other bodies outwith the Institute.

Forty-five fresh and weathered rock samples, collected by the Department of Mineral Soils, have been sectioned at their request.

A set of 15 samples of soil crumbs, for which the structural stability had been altered, were impregnated and sectioned at the request of the Department of Civil Engineering, Glasgow University.

Some 90 large soil thin sections have been prepared and examined from a 6·5 m exposure, on the north face of Kirkhill Quarry, near Mintlaw

to the north of Aberdeen. This unique site shows a sequence of fluvioglacial sand, tills and solifluction deposits, within which palaeosols have been described. The micromorphology of this site has been investigated in collaboration with Mr R. Connel, University of Aberdeen. The distribution pattern of oriented clay in soil pores, together with the presence of silt droplet structures, and small stones showing weather rims, has confirmed the presence of more than one palaeosol.

Following discussions with the Scottish Crop Research Institute, a range of soil materials, artificially inoculated with nematodes, was freeze-dried, impregnated and sectioned. Using optical microscopy it was possible to see nematodes in the thin sections, and in some cases sufficient morphological detail was apparent to make specific identification possible. This method may have an application in studies concerning the ecological niche occupied by nematodes within undisturbed soil materials. A short joint note on the technique has been submitted to Revue de Nématologie.[8]

A joint paper on Optical, Scanning Electron Microscopic and Micro-Analytical Study of Cementation in some podzols[9] was presented by Dr W. J. McHardy at the Second Workshop of the International Working-Group on Soil Microscopy of Undisturbed Soil Materials, in Poitiers, France, and has been accepted for publication.

In collaboration with the Department of Microbiology, investigations are underway with regard to the macro- and microporosity of selected soil materials. Undisturbed soil samples, impregnated with polyester resin containing a fluorescent dye, were examined optically under epi-illumination using a combination of white and ultraviolet light. Following precision grinding and accurate sample re-location methods, serial drawings showing pore distribution at a spacing of ca. 10 microns were built up. Both manual and computerised techniques are being used in an attempt to create a three dimensional picture of the soil microporosity, and in particular to evaluate the degree of continuity of the micropores. Problems have been encountered with sample distortion during drying and several drying and pre-drying fixation methods are being investigated.

The presence, in a range of soil materials, of cyst-like objects has been further investigated. None of the information available to date, on their morphology and survival characteristics is incompatible with their being spore cases of vesicular-arbuscular mycorrhizae and considerable information as to their occurrence and distribution in a range of Scottish soils has been accumulated. This information appears to be of particular value in an archaeological context, where an analysis of these objects may provide information relating to prehistoric patterns of livestock farming. This will be discussed in a paper being prepared for presentation at a conference on " Settlement in North Britain 1000 B.C. - A.D. 1000 " to be held at the University of Newcastle upon Tyne in December, 1982.

An account of the soils encountered during the excavation of a large barrow at Strathallan, Perthshire[10] will be published as part of the excavation report by the Scottish Development Department. 804

Data Processing

To assist with the setting up of a data base to handle both general and specific soils information within the Department, two Apple 2 microcomputers have been installed, together with the essential ancillary equipment.

Computer programs have been written to facilitate the preparation of hardcopy graphs of optically derived data, with particular reference to micromorphological work being carried out on the distribution of oriented clay in Scottish soils.

With regard to the Soil Monolith Library, a data base has been set up and all available data from the previously used card index has been transferred to magnetic disc. This will result in a much more efficient method of data modification and addition, with hardcopy printouts of selected information being readily available. A complete index of the Library contents, sorted in numerical, Soil Association and Genetic Soil Group order, has been prepared for reference purposes.

Transfer of all soil maps and memoirs stocks from Ordnance Survey to the Soil Survey of Scotland is at present underway and a trial stock control system has been set up. 801, 804

Other Work

There has continued to be a good level of collaboration with the Department of Agriculture and Fisheries for Scotland, particularly in matters concerning assessment of land capability for agriculture. With its acceptance by DAFS and SDD, training courses have been held in most regions to introduce DAFS officers to the Survey's revised classification. Co-operation with DAFS and the National Coal Board has been extended, involving surveys of existing and proposed open-cast extraction sites, and *ad hoc* consultative groups have been established, including representatives of DAFS, NCB, the East and West Agricultural Colleges and the Soil Survey.

Collaboration with the three Scottish Colleges has continued, particularly in the supply of soils information for drainage and reclamation schemes, with the Hill Farming Research Organisation on a re-seeding monitoring project, with the Scottish Institute of Agricultural Engineering, the Scottish Crop Research Institute, the Forestry Commission, the Nature Conservancy Council and the Soil Survey of England and Wales.

Within the Institute collaboration with other departments has included the regular collection of stream-water samples from selected areas in three regions for the Department of Mineral Soils and from the Strath of Kildonan for the Department of Spectrochemistry, participation in an inter-departmental project to investigate ochre deposition in field drains and, with the Department of Microbiology, investigation of techniques for examining microporosity of selected soils.

Assistance has been given to a number of Regional and District Councils, particularly the Highland Region, in association with the Highlands and Islands Development Board, in the monitoring of a commissioned survey of the potentially reclaimable land in the Beauly Firth.

Field demonstrations and talks on the work of the Soil Survey have been provided for various departments of the Universities of Aberdeen, St Andrews, Strathclyde and Stirling and other parties of visitors, and a one-week visit to Scotland was organised for a 28-strong party from the Agricultural University, Wageningen, Netherlands, including local excursions and a three-day tour to demonstrate soil, landscape, land-use and climatic conditions in Scotland.

Exhibits of the Soil Survey's maps and other publications, provided for the Royal Highland Show and the Turriff and Lorne Agricultural Shows, were highly successful in stimulating public interest in the work. The Department has continued to deal with many requests for information and assistance on a wide range of applications of its work.

Mr J. S. Bibby provided an interview on Land Capability mapping for a BBC agricultural programme.

Papers on soil survey and its interpretation for agriculture in the West Highlands[11], native pinewoods in Abernethy Forest[12], the European SAR-581 experiment[13] and eluvial/alluvial coefficients of major elements[14] have been published, and one on soils and their related management problems in the Carses of Earn and Gowrie[15] has been accepted for publication. 801, 802, 804

Maps, Memoirs and Cartography

The following one-inch maps have been published in both flat and folded versions: Sheet 47 Crieff (Land Use Capability)[16] and Sheet 75 Tomintoul (Soil)[17]. The colour proofs of Sheet 47 Crieff (Soil) have been examined and returned to Ordnance Survey for final printing.

All seven 1:250 000 soil maps[18] have been printed and the stock has been delivered to Aberdeen. All seven 1:250 000 Land Capability for Agriculture colour proofs[19] have been checked and returned to Ordnance Survey for final printing.

Work has started on the typesetting of the explanatory handbooks for the 1:250 000 maps. Plans to set the type for these handbooks within Soil Survey drawing office have had to be revised and much of the type-setting will now be carried out by local printers. The preparation of diagrams and screened half-tone prints for the handbooks is now complete.

A 1:625 000 scale map, Assessment of Climatic Factors in LCA in Scotland has been printed by Ordnance Survey from negatives supplied by Soil Survey. A monograph to accompany the folded version of this sheet is at the final stages of printing.

Restricted circulation maps on 1:10 000 scale were prepared for Loch Lomond Nature Reserve and for Ponesk Open-Cast Coal Extraction site, Strathclyde Region.

Exhibitions of Soil Survey work were held at the Royal Highland Show, Ingliston, Edinburgh, and at the British Cartographic Society symposium at St Andrews University; most of the exhibition material was prepared in the Soil Survey drawing office. 801

SOILS OF CRIEFF AND DISTRICT

Although fieldwork on Sheet 47 (Crieff) has been completed, much analytical work has still to be done. It is, however, possible to give a general account of the geology, climate, soils and land-use of the district.

The area surveyed comprises some 432 square miles (1118 km²) in West Perthshire, now largely in Tayside Region with a small part of the western margin in Central Region. The boundaries are shown in Fig. 9.1.

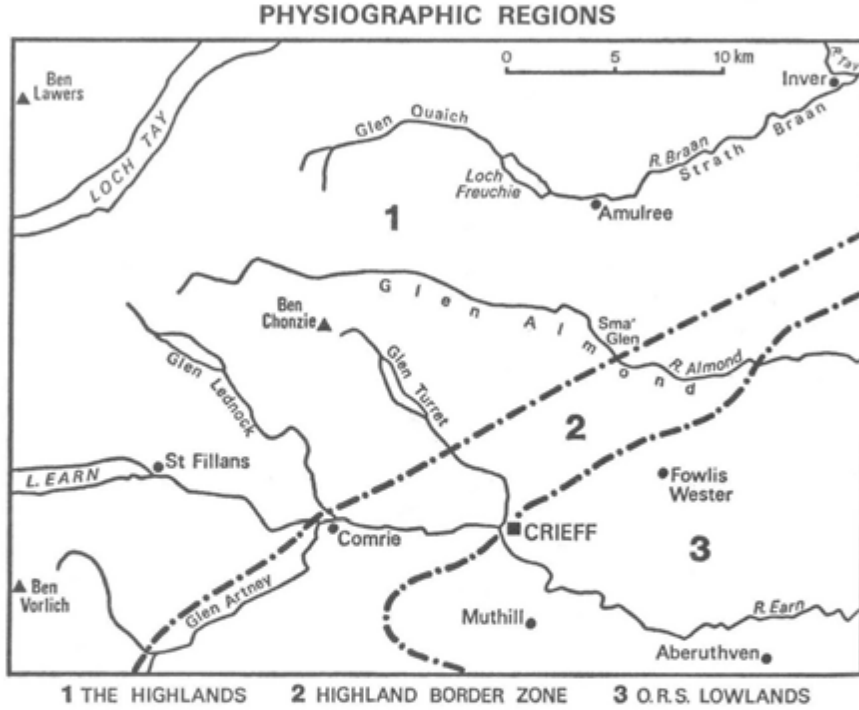

Fig. 9.1.

The small burgh of Crieff lies just south of the centre of the area and is the principal settlement; the main market centres are Perth to the east and Stirling to the south.

Two major regions of Scotland, the Highlands and the Midland Valley, are represented within the area. The former is the most extensive and is separated from the latter by the Highland Boundary Fault. Three maior physiographic regions are apparent:

1. The Highlands.
2. The Highland Border Zone and Old Red Sandstone Uplands.
3. The Old Red Sandstone Lowlands.

Geology

The solid rocks underlying the area are mainly acid metamorphic slates and schists of the Dalradian Series of Highland Schists north and west of the Highland Boundary Fault and Lower Old Red Sandstone sediments south and east of the fault. Along the Highland Border Zone or relatively close to it there is a series of small igneous instrusions of various types with occasional extrusive igneous rocks associated with them.

Slates and schistose grits are the hardest metamorphic rocks present and tend to underlie the highest summits; Ben Lawers 3986 feet (1214 m); slates, Ben Vorlich 3224 feet (983 m) and Ben Chonzie 3048 feet (929 m); schistose grit and form the steepest slopes; the steep Highland edge is largely underlain by a band of slate.

The Old Red Sandstone Uplands are largely underlain by conglomerates and sandstones, either lying vertically close to the Highland Boundary Fault or steeply dipping south-eastwards away from it to form the northern limit of the broad syncline which underlies the lowland area.

The Old Red Sandstone Lowlands are gently undulating and underlain by sandstones, marls and mudstones with occasional intrusive basic igneous dykes of probable Permo-Carboniferous age forming occasional prominent, but relatively unimportant, ridges running east-west across it.

The whole area has been glaciated and this has resulted in the development of many distinctive soil parent materials, namely glacial tills, moraines and fluvioglacial deposits. Post-glacial fluctuations in sea level have resulted in the formation of inland raised beach deposits the most recent of which are basin and hill peat and riverine alluvium.

The geological succession is:

Recent	Peat and alluvium
Post-glacial	Raised beach deposits
Pleistocene	Solifluction deposits, fluvioglacial sands and gravels and till deposits
Permo-Carboniferous	Basic igneous dyke intrusions
Old Red Sandstone	Lower O.R.S. igneous intrusive rocks and sediments — conglomerates, sandstones, marls and mudstones
Dalradian Series of Highland Schists	Mainly acid micaceous schists and slates.

Climate

The climate of the area is strongly influenced by the east-west trend of the main valley systems which ensures that strong air mass influences from either west or east may temporarily prevail at any season. The westerly airflow is more evident in the autumn and winter when the area is influenced

by the frequent passage of well developed Atlantic depressions. These winds carry a heavy rainfall and the highest hills in the west and north-west of the area receive average rainfall well in excess of 1800 mm per annum. This drops to 1400 mm in the main valleys and 1200 mm around the fringes of the foothills. In the lowlands of the western part of the area around Comrie rainfall is as high as 1250 mm, whereas in the extreme east values decline to c. 800 mm around Aberuthven. December is the wettest month with the driest period from March to July.

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

In the Earn valley the mean monthly maximum temperatures rise by almost 14°C from 5·0 to 18·9°C between January and July. In the surrounding hills and valleys the temperature is modified by relief with a depression of summer maxima. Snowfalls are most frequent in the first quarter of the year with snow lying in the lowlands for an average of just over two weeks, whereas in the highest hills it is likely to remain for several months. Bleak conditions are also apparent at relatively low elevations in the foothills, about seventy air frosts per year being recorded with a high frequency during the critical growing period in April and May.

Soils

Ninety-three soil series and nine soil complexes have been mapped and are grouped into the following eighteen soil associations:

Association	*Parent Material*
Foudland	Drift derived from slates and argillaceous schists of Dalradian Series of Highland Schists
Strichen	Drift derived from acid micaceous schists and schistose grits of Dalradian Series of Highland Schists
Aberlour	Drift derived from an intermixture of acid schists, granitic and felsitic rocks of Dalradian Series of Highland Schists
Gourdie	Till derived from an intermixture of Dalradian Series rocks and Lower Old Red Sandstone sediments and lavas
Callender	Till derived from an intermixture of Dalradian Series rocks and Lower Old Red Sandstone sediments
Stonehaven	Drift derived from Lower Old Red Sandstone conglomerates
Balrownie	Till derived from Lower Old Red Sandstone sediments, mainly sandstones, flags and mudstones with some Highland Schist erratics
Laurencekirk	Till derived from Lower Old Red Sandstone marls and mudstones
Forfar	Water-sorted material generally >60 cm overlying till derived from Lower Old Red Sandstone sediments

Sourhope	Drift derived from andesitic and intermediate lavas of Lower Old Red Sandstone age
Insch	Drift derived from basic dioritic igneous rocks
Darleith	Drift derived from basaltic lavas and intrusive igneous rocks of probable Permo-Carboniferous age
Corby	Fluvioglacial sands and gravels derived from acid Highland Schist rocks
Doune	Fluvioglacial sands and gravels derived from Highland Schist rocks and Lower Old Red Sandstone sediments and lavas
Gleneagles	Fluvioglacial sands and gravels derived from Lower Old Red Sandstone sediments and lavas with some Highland Schist erratics
Nochty	Fluvioglacial sands and gravels derived from basic igneous rocks with some acid schist and granitic erratics
Carpow	Raised Beach sands and gravels of Old Red Sandstone sediments and intermediate lavas
Carbrook	Estuarine High Raised Beach silts and clays.

MAJOR SOIL GROUPS

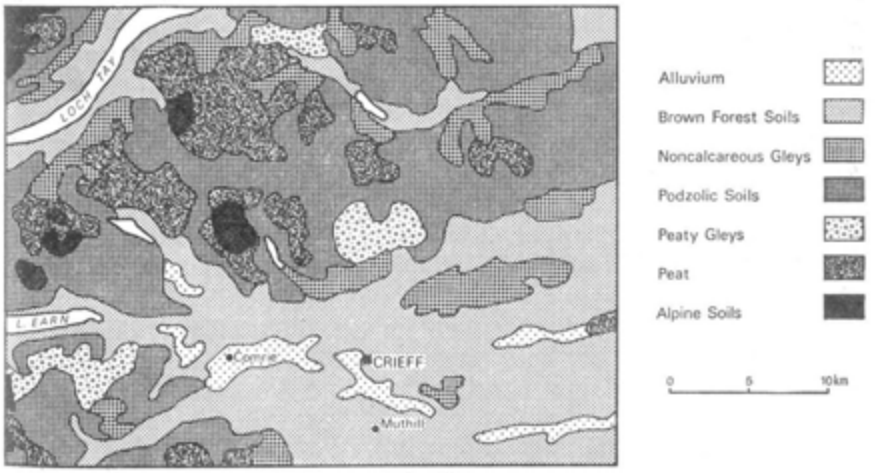

Fig. 9.2.

In addition the following miscellaneous soils have been mapped:

Basin and Valley Peat } Subdivided where practicable into two categories
Blanket Peat } according to depth, i.e. 50-100 cm and >100 cm

Peat-alluvium complex

Alluvial fan soils

Recent riverine and lacustrine alluvial soils.

The major soil groups of the area are shown in Fig. 9.2.

The most extensive group of soils, the Strichen Association, accounting for about 39 per cent of the area, comprises thirteen soil series and six soil complexes developed on parent materials derived from acid meta-

morphic rocks of the Dalradian Series of Highland Schists. Covering most of the Highlands area the association is dominated by two major soil groups, the brown forest soils on the lower steep valley and hill sides and gley soils occupying gentler valley sides in the climatically wetter areas. Brown forest soils, most of which are acid brown earths, account for almost 25 per cent of the association and gley soils, most of which are peaty gleys, just over 25 per cent; podzolic soils, mainly humus-iron podzols, make up just over 20 per cent and shallow stony rocky soils, mostly podzolic rankers, just under 20 per cent of the association.

The drift on which most of the soils are developed varies from loamy till, often of sandy clay loam texture, in the valley bottoms and on lower hill slopes through loamy colluvium on the steeper slopes to coarse stony and sandy detritus on the summit plateaux and ridges. Coarse stony moraine is also often present on lower valley sides and in main valley and high level corrie bottoms. The principal rock types from which these drifts are derived are quartz-schists, quartz-mica-schists, chlorite-mica-schists and schistose grits, all very acid and low in nutrient minerals and trace elements. The resulting soils are naturally acid and low in nutrients, but in climatically and topographically suitable areas can be cultivated successfully to grow good grassland and some arable crops. Such areas, however, are usually confined to lower hill slopes and valleys sheltered from the extremes of the normally wet and windy Highland climate, especially in seasons other than summer.

Other soil associations occurring in the Highlands are Foudland, Aberlour, Insch, Corby and Nochty. Of these, Foudland soils are the most extensive accounting for 6 per cent of the area being described whereas Insch soils occupy only 2 per cent, Corby soils 2 per cent, Aberlour soils 1 per cent and Nochty soils less than one quarter of 1 per cent of the area.

The soils of the Foudland Association are fairly similar to those of the Strichen Association, but since they are developed on drift derived from hard slaty rocks they tend to occur on steeper slopes in areas of higher resistance to erosive agencies. The drift is generally smoother textured, even although the rock fragments in it are not readily weathered. The pattern of soils is slightly different with brown forest soils — again mainly acid brown earths — not so dominant although still important (just under 20 per cent) and podzolic soils more important (almost 30 per cent) and gley soils—mainly peaty gleys—just under 20 per cent of the association. The soils are generally more acid than those of the Strichen Association and are equally low in natural nutrients and trace elements and prone to deficiences if not managed carefully, especially along the Highland edge.

The soils of the Insch Association are limited to a relatively small area in Glen Lednock around Invergeldie and extending onto the lower slopes of Ben Chonzie. As would be expected from a basic parent material most of the soils are brown forest soils, but many of them are shallow with rock close to the surface if not actually outcropping. The brown soils extend well up the hill to over 1500 feet (460 m) and support good rough grazings

at the higher altitudes and improved permanent pasture on the lower cultivable slopes. Associated with these basic soils in the valley bottoms are fluvioglacial sands and gravels derived from similar basic rocks. They are not extensive but have been separated as soils of the Nochty Association.

The soils of the Corby Association are confined to the major valley bottoms in the Highland area such as Glen Almond, Glen Quaich and Strath Braan. They are mainly brown forest soils developed on fluvioglacial sands and gravels derived from acid metamorphic rocks of the Dalradian Series of Highland Schists. Although stony they can sustain arable crops and long ley pasture in the more favourable climatic areas and good permanent pasture in the less favourable, generally wetter, areas. Where they occur in minor upland valleys the gravels have podzolic soils developed on them and it is possible to improve some of these from rough grazing to better quality permanent pasture.

The soils of the Aberlour Association are relatively minor in extent and occur close to acid igneous intrusions within the Highland area where these intrusive rocks are incorporated wth the more normal acid metamorphic rocks from which most of the drift is derived. The mixed drift soils are generally coarser textured and more acid than those of the Strichen Association and the dominant soils are thus podzolic. Those favourably situated support permanent pasture or good rough grazing but many of them occur in climatically or topographically unfavourable areas and are thus limited to supporting very rough grazing.

Organic soils are also important in the Highland area and occupy almost 160 km^2 within it. This represents almost 15 per cent of the total area under discussion and most of it is blanket bog or hill peat. Many of the plateau-like upland areas are covered by peat in excess of 2 metres depth. Erosion has taken place on several hills and hagging is common, but not universal throughout the area. Most of the grazing is very rough and of only short duration each summer.

Immediately south-east of the Highlands and the Highland Boundary Fault is a series of Lower Old Red Sandstone sediments forming the foothills of the Highlands and best referred to as the Old Red Sandstone Uplands. Closest to the fault the rocks are softer sandstone and tend to form a trough which is confined to the south between Glen Artney and the Small Glen by a series of rounded hills underlain by vertical beds of harder conglomerate. None of these hills, Torlum 393 m. (1291 ft.), the Knock of Crieff 278 m. (912 ft.) and Milquhanzie Hill 350 m. (1153 ft.) is very high, but all are prominent in the landscape. Along this part of the fault zone basic igneous intrusions are also evident and frequently provide spectacular rocky scenery in an otherwise rounded topography. The Highland Border zone and Lower Old Red Sandstone Uplands are rarely more than 3 miles (5 km.) wide. They include some of the most complex soil patterns found in the district with the soils developed directly from the underlying rocks or on the many variants of the drifts derived from them.

The soils of this complex pattern have been grouped into six associations, none of which is very extensive, but the sum of them amounts to 11% of the area. The most widespread of these is the Gourdie Association whose soils are developed on a mixed till derived from the acid metamorphic rocks of the adjoining Highlands, the Lower Old Red Sandstone sediments which immediately underlie them and the nearby basic igneous intrusive rocks which contribute to the drift in their immedate vicinty. Brown forest soils, most of whch are acid brown earths, account for almost 60 per cent of the Association. These are almost equally divided into freely drained stony variants developed on a loamy textured till mantling moderate and fairly steep slopes, and imperfectly drained less stony variants developed on sandy clay loam till on moderate and gentler slopes. In spite of the contribution to the drift from igneous rocks the trace element content of these soils tends to be low and cobalt and copper deficiency problems are not uncommon, especially in areas of reclaimed grassland where the application of lime has inhibited the availability of trace elements. Gley soils account for almost 35 per cent of the association and occur on the gentler slopes and depressions underlain by sandy clay loam till. They are drainable, but are also prone to trace element problems if not managed carefully. Podzolic soils occur on the drier sites nearer the Highland Boundary Fault but are not very extensive.

Associated with the Gourdie Association are the very similar soils of the Callander Association. The main difference between them is that in the Callander Association the acid metamorphic rock contribution to the mixed drift is slate rather than acid schist and the igneous rock contribution is absent. The pattern of soils is very similar to that of the Gourdie Association except that the dominant soil tends to be the imperfectly drained variant of the acid brown earth and the underlying till is almost always loamy textured with a high fine sand fraction.

The Doune Association occupies much of the lowest ground in the trough between the Highland Boundary Fault and the confining hills to the south. The soils are mainly free draining acid brown earths developed on fluvioglacial sands and gravels derived from a mixture of acid metamorphic Highland rocks, Lower Old Red Sandstone sediments and basic igneous intrusive rocks and they frequently provide some of the best agricultural land in the area where they occur. Their use can, however, vary from good arable land to moderate rough grazing depending on their situation and extent.

The soils of the Stonehaven Association developed on drifts derived from Lower Old Red Sandstone conglomerates occur on the highest parts of the Old Red Sandstone Uplands. The dominant soils are podzolic in nature, usually shallow and stony and occupy variable slopes which are often locally steep. Thus their use is largely confined to rough grazing and forestry.

Similarly the soils of the Darleith Association, developed on drifts derived from basaltic lavas and intrusive igneous rocks, occur on some of the higher parts of the foothills and uplands. The dominant soil in this

Association is a freely drained acid brown earth developed on stony loamy drift which is frequently shallow and occupies variable slopes that can support good quality grazings, although, on one estate, some of the soils have been managed for grouse moor.

The soils of the Sourhope Association are of very limited extent and confined to the southern side of the entrance to Glen Artney. They are dominantly free draining acid brown earths and occur on some fairly steep slopes so their use is limited to grazing and forestry.

The second most extensive group of soils occurring in the district, the Balrownie Association, is the most important in the lowlands. It occupies some 12 per cent of the whole area and more than half of the lowlands and comprises ten soil series and one soil complex developed mostly on till derived from Lower Old Red Sandstone sediments, mainly sandstones, but including finer grained flagstones and mudstones.

Where it abuts on the uplands the Association includes podzolic soils but in total they account for only 10 per cent. The most extensive and most important soils are the brown forest soils which make up almost three quarters of the Association. The free draining variants account for 31 per cent of the Association and the imperfectly drained over 43 per cent. Gley soils account for 14 per cent of the Association and are mainly confined to those areas adjacent to the uplands but they do occur elsewhere too.

The most widespread and important soil is the Balrownie Series which occupies almost 50 km². With a dark reddish brown loamy topsoil some 30 cm thick it provides probably the best growing medium in the district for a wide variety of crops which include soft fruit, brassicas, roots, cereals and grass. The water-modified reddish brown subsoil overlying only moderately structured red-brown sandy clay loam till provides reasonable drainage and aeration in wetter periods of the year and a deep reservoir of moisture during the drier periods. Although not naturally rich in plant nutrients, the soil responds well to fertilizer input and is not difficult to keep at the appropriate pH levels for the range of crops grown. It does, however, need careful management in the climatically wetter areas where it occurs and in wet seasons.

Almost as widespread and important is the Buchanyhill Series which occupies some 40 km². This soil differs from the Balrownie Series mainly in its free natural drainage and in being developed on red sandstone rock rather than till. Its depth is variable but there is usually a reddish brown water-modified sandy subsoil between the dark reddish brown loamy topsoil and the red sandy bedrock. In areas where the subsoil is thicker than 30 cm the soil behaves very similarly to the Balrownie Series, but where the subsoil is shallow the soil is prone to "burning" in dry periods. On steeper valleyside sites the series is mostly used for grass, but elsewhere a similar range of crops to that of the Balrownie Series can be grown. In areas at altitudes greater than 150 m it tends to be kept in grass for fairly long periods.

The Kippendavie Series is similar to the Balrownie Series except that it is generally a heavier soil with its subsoil rarely water-modified and the

underlying till usually a clay loam texture rather than a sandy clay loam. Water movement down the profile is thus much slower than in the Balrownie Series and more careful management is required to maintain optimum crop yield with minimum damage to the soil. The soils of this series frequently require some subsoil disturbance to improve aeration and permeability and so make them easier to manage for arable agriculture.

The gley soils of the Association, mainly Lour Series, are essentially poorly drained variants of the Balrownie or Kippendavie Series underlain by a clay loam till occurring on relatively flat sites with little or no lateral run-off of excess water. Such sites are difficult to manage for arable agriculture, even after comprehensive drainage and most have been planted with coniferous trees as at Keillour Forest, Innerpeffray Wood and on the Gask Estate.

Associated with soils of the Balrownie Association are those of the Forfar and Laurencekirk Associations. The soils of the Forfar Association

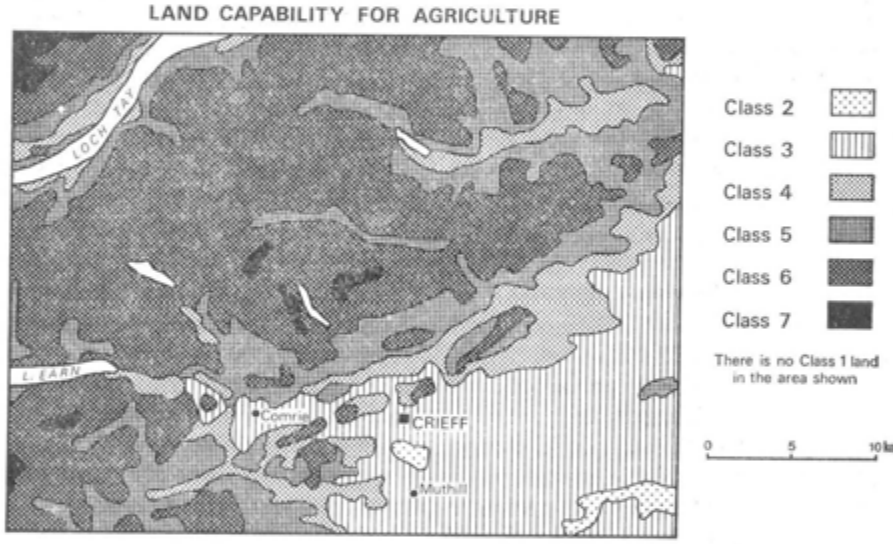

Fig. 9.3.

are developed on water-modified drift at least 60 cm thick and generally underlain by loamy till at depth, whereas those of the Laurencekirk Association are developed on till derived from marls and mudstones. The former are thus very sandy soils and the latter silty soils, both are loamy and provide excellent media for the growing of arable crops.

The raised beach deposits along the present Earn valley and the former Earn valley, now occupied by the misfit Pow Water, are of two types, sands and gravels (Carpow Association) and silts and clays (Carbrook Association). Both occur at altitudes ranging from 75 feet (25 m) to 125 feet (40 m) above sea level. The silts and clays tend to be at the lower level and frequently underlie some of the sands and gravels occurring upslope from them. Soils of the Carbrook Association are commonest in the Earn valley between

Kinkell and Dalreoch Bridges, but are also present in the Pow valley near Madderty. Soils of the Carpow Association are common in the Earn valley between Kinkell Bridge and Crieff and also along the whole length of the Pow Water. Although occupying only 2 per cent of the total area, the soils developed on them are important agriculturally and provide some of the best crop yields in the district.

The alluvial soils present in the district account for some 6 per cent of the total area. They are very variable in texture and natural drainage, but frequently provide some of the best agricultural land in the areas of their occurrence if they are not too subject to flooding. This is especially so along the whole length of the Earn valley and its tributary streams and also applies to Strath Braan and to a lesser degree Glen Almond.

Land Use and Agriculture

The distribution of land capability classes for agriculture for the district is shown in Fig. 9·3. The area and proportion of the land capability classes is shown in the table below:

Class 2	45 km² (4%)
Class 3	165 km² (15%)
Class 4	135 km² (12%)
Class 5	230 km² (21%)
Class 6	450 km² (40%)
Class 7	60 km² (5%)
Built-up area and open-water	33 km² (3%)

The majority of the productive arable soils of the area are included in Land Capability Class 3 with only limited areas of Class 2 confined to the coarser textured soils of the sandy raised beaches (Carpow Series), and water-modified tills (Balrownie and Luther Series) and some sandy alluvial soils in the Earn valley.

The imperfectly drained series of Balrownie Association have been included in Class 3ws because of the wetness of these soils at critical times of the year such as seed-time and harvest. Careful management is needed to ensure minimum damage to soil structure by working these soils only when conditions are suitable. The finer texture and consequent longer periods of wetness of the poorly drained series of the Association make successful cultivation very difficult and these soils are included in Class 4w. Many of them have been afforested.

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

In the upland areas of the Highland Border Zone and around the Old Red Sandstone conglomerate hills at altitudes from about 180 m to about 500 m, the slopes are too steep and too high for arable cultivation and are kept in permanent pasture. Most soils are included in Class 5 provided

the rainfall is <1500 mm per annum. In the higher altitudes of the Highlands more severe exposure, excessive rainfall and restricted growing season limit the shallow peaty soils and blanket peat deposits to Class 6. On the very high hills the very restricted growing season limits agricultural land use to a very short summer rough grazing season appropriate to Class 7; areas of scree and rock outcrops are also included in Class 7.

The wide range of soils which occupy the area have a marked influence on the variety of agricultural enterprises. In the drier east and south, arable crops are the most important, but in the wetter west and upland areas grassland production provides much of the feed for livestock consumption on the farm. Both rotational and permanent grassland make a major contribution to livestock production in the area. The extensive Highlands area of predominantly heather moor also contributes to the summer grazing of the important sheep enterprises, although the extent of this varies from a possible stocking rate of about one sheep per acre of the better areas of hill grazing, which include considerable areas of grassland communities, to about one sheep per 5 acres in the worst areas of heath and bog vegetation. Deer farming is carried out on a limited scale for the export of venison and associated products and the integration of sporting activities, especially for foreign tourists, is begining to develop successfully. 801

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10. TECHNICAL SERVICES

A. W. STUART

The past year has again been a busy one for all four sections of Technical Services.

Several new items of equipment have been acquired: a Universal Milling Machine with a 3 axis Digital Readout (DRO) System, to provide greater machining facilities with repeatable positioning, for use in the Instrumentation Section; an Optical Head for the printed circuit board drilling machine, and a new tinning bath, necessary for the faster production of printed circuit boards designed by the Electronic Section. A Wild Photomakroskop has also been bought to enable the Photographic Unit to carry out work in macrophotography.

A summary of the work undertaken by the individual sections is given in the following paragraphs.

Instrumentation

Over 200 catalogued items of work have been carried out though, due to staffing difficulties, delays have been inevitable during the past year.

Spectrochemistry. The construction of a jewelled nebulizing chamber is now in its final stage, and work has started on a constant temperature gas controller with stepper motor controlled valves. Both units are required for the Inductively Coupled Radiofrequency Plasma project.

Mineral Soils. An automatic sample change unit for use with a Philips X-ray Spectrometer has been completed.

Peat and Forest Soils. Further digestion blocks were produced for the rapid cooling of samples and a rotating platform with tilting device was designed and constructed to accommodate specialised sampling tubes, for use in the acid rain experiment at Balquhidder.

Electronics

The Electronic Section has been kept very busy throughout the year, most of the work being concerned, as usual, with the maintenance of laboratory equipment. Fewer requests were received for new instrumentation, partly due to the present backlog of work on large projects.

Work on the Dionex Ion Chromatogram is now complete and good progress is being maintained on other major projects.

Photography

Over the winter the Photographic Unit, in conjunction with the Department of Peat and Forest Soils, provided aerial photographs for the High-

lands and Islands Development Board of selected sites in the Grampian Mountains, in order to monitor the snow cover of proposed ski runs.

The Unit also assisted in the "Great Glen Expedition," by providing vertical stereo photography of experiments over the Beauly Firth from the Goodyear Airship "EUROPA." A special external camera platform was constructed by the Goodyear engineers for this purpose (see 10.1 and 10.2).

Fig. 10.1.
Goodyear Airship "Europa" arriving at Dalcross Airport, Inverness.

Fig. 10.2.
Mr J. Mitchell attaching the aerial camera to the external rig on the "Europa."

Joinery/Building Maintenance

This Section has also been very active during the past year, carrying out the refurbishment of various rooms throughout the Institute and tackling many maintenance projects.

Spectrochemistry. Room 154 was divided into two laboratory areas. One is air conditioned and houses the Plasma Arc Unit, a Spex Spectrometer and associated computer equipment, while the other is maintained at a slight positive pressure so that it can be used as a clean room for sample preparation. Seven sink units in the Department of Spectrochemistry's four main preparation laboratories have also been refurbished.

Soil Fertility. Room 284B has been altered to house new fume cupboards and a fume extraction system.

Soil Survey. The old store in the basement of Craigiebuckler House has been upgraded to meet the requirements of the Department of Soil Survey.

General Maintenance. The resealing and painting of external windows throughout the Institute is progressing steadily, with approximately one-third of the total number of windows completed. Four new water valves and a fire hydrant were installed to improve the control of mains water supplies to Craigiebuckler House and the various outbuildings and the complete rewiring of the canteen and dining area of Outbuilding F was also undertaken.

11. LIBRARY

A. H. W. Dickie

The Library was very busy throughout the year, being used extensively by staff and visiting research workers. Loans have been made to individuals and institutions, either directly or through the national inter-lending system. Last year 118 items were lent to other libraries and a total of 825 items were borrowed, of which 461 came through the British Library Lending Division.

315 books were bought or donated and, by cancelling subscriptions to four journals, the Institute has been able to subscribe to 10 others.

Two Current Awareness publications are provided — a weekly Periodicals Bulletin and a monthly Book Bulletin. Both are primarily for internal circulation, but copies are also distributed to the other Scottish Agricultural Research Institutes and to local research establishments.

A List of Publications appears at the end of this Annual Report. Both reprints and separate copies of the Lists can be obtained from the Librarian. In response to the last List circulated in June, 1982, there have been 369 requests for reprints so far. 703 reprints were also distributed in response to general requests.

APPENDIX I

SEVENTH

T. B. MACAULAY LECTURE

26th November, 1982

by

Professor J. TINSLEY, F.R.S.C., F.R.S.E.

Chairman:

Professor T. C. Phemister, M.Sc., Ph.D., D.Sc., F.R.S.E.

SEVENTH T. B. MACAULAY LECTURE

Aberdeen, 26th November, 1982

BOUNDARY MARKERS OF SOIL SCIENCE

Professor JOSEPH TINSLEY, F.R.I.C., F.R.S.C., F.R.S.E.

Department of Soil Science,
University of Aberdeen

INTRODUCTION

It is indeed an honour for me to give this lecture. My connections with Aberdeen began in 1936 when, as an undergraduate student at Reading, I spent two months of the summer vacation working at the Rowett Institute, where it was my privilege to meet Sir John, later Lord Boyd Orr. One afternoon I paid a brief visit to Craigiebuckler House and met Dr Ogg, later Sir William. After the War I came back in 1951 for a short visit, primarily to consult the late Dr R. L. Mitchell on developments in flame spectrophotometry and I also remember seeing the decrepit state of the old Chemistry Building under construction in Old Aberdeen. My third visit was for interview in 1958, as the result of which Aberdeen became our home and over the years I have developed a great affection for the Granite City.

Let me explain my choice of title: In the Queen's Silver Jubilee year, 1977, I received a fascinating brochure from the Town House entitled "The Freedom Lands and Marches of Aberdeen."[10] This describes how King Robert the Bruce, in 1319 (five years after Bannockburn), gifted his hunting lands of Stocket Forest to the City Burghers as a reward for their loyalty and stout defence against the English. Fuller details are contained in a book of this title[37] published in 1927.

Originally some 25 square miles were bounded by 10 "gret grey stanes" presumably granite boulders; but around 1578 "new maid saser stanes" were put in place and towards the end of the 18th Century it was decided

to mark the boundaries more accurately. By 1810 there were 67 stones in place and each year until 1889 the Lord Provost and city dignitaries " rode the marches " on horseback or in carriages. Don't quote me, but maybe the Lord Provost now drives round at Hallowe'en in his Phantom Rolls!

The map of the stone locations[10] from A to Ω also shows how Aberdeen District now extends well to the north of the Don and south of the Dee, but in the West it follows the original 1319 line.

Fig. 1.
March stone 33 beside older cup stone.

Fig. 1 depicts March Stone 33 standing erect beside the earlier cup stone. It is presumed the cup originally contained lead bearing the city seal. This particular pair lie in a field near Clinterty House, a few yards from the public path leading over Elrick Hill and not far from Greenwell-tree Farm, where a very successful deep drainage system was installed over 30 years ago.

About 100 m away, inside the boundary, lie the tracks of the newest gas pipeline laid in 1982 and the original oil pipeline, 1974.

My predecessor in the University, Dr Horace Williamson[81], in his presidential address to the British Society of Soil Science in 1958, stoutly defended the view that Soil Science has valid claims to be recognised as a distinct discipline. Fig. 2 from my inaugural lecture a decade ago[69] indicates how the academic core of soil studies, commonly termed Pedology, overlaps with and depends on basic physical, biological and earth sciences. It also points to the important practical aspects of land use for cropping and other purposes.

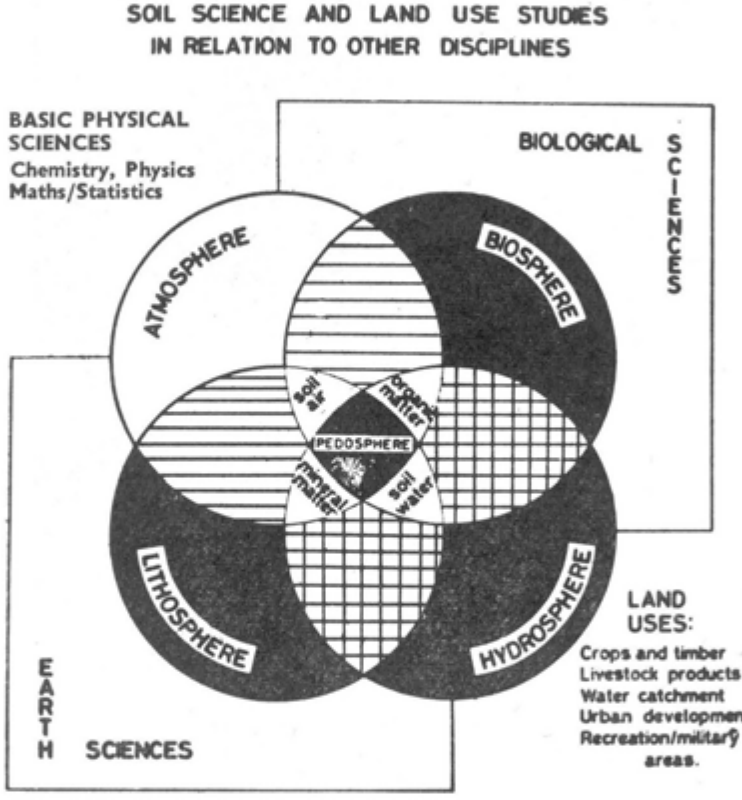

Fig. 2.

Today, I hope to portray a succession of individuals whose achievements in the past have, in my mind, become historic reference marks along the expanding boundaries of soil science; some of them I have been greatly privileged to meet personally. In the main I shall refrain from comment on the work of colleagues and friends who are still active in their researches, but towards the end I may briefly speculate on a few likely trends in the future. The best single reference on early ideas of soil fertility and plant growth up to the middle of the 19th C. is the " Sourcebook of Agricultural Chemistry " by an American, Charles Browne[7], published in 1944. Sir

John Russell's book "History of Agricultural Science in Great Britain"[56] is a mine of information: it was completed only a few weeks before he died in 1966, aged 94[68]. My choice leans towards Scottish personalities and includes relatively few from outside Europe.

The 17th and 18th Centuries

We can start with the great Francis Bacon for in his book "Sylva Sylvarum," published posthumously in 1651[3], are described experiments to test the effects of various solutions on the growth of wheat seedlings. Sir Francis declared that nitre (saltpetre) is the "*life of vegetables*" and that "*fat earths protected from sun and rain left to themselves will soon abound in nitrous salt*". Robert Boyle[9], author of "The Sceptical Chemist" (1661), also was well aware of the fertilizing value of nitre, but the incessant demand for gunpowder claimed all available supplies. The late Dr Crowther[12] had a good deal more to say about Boyle in his presidential address of 1953, entitled "The Sceptical Soil Chemist".

Time does not allow discussion of the elegant work of the medical doctor Francis Home[25] in Edinburgh, whose book "Principles of Agriculture and Vegetation" appeared in 1757. Instead I move to the French chemist Lavoisier who knitted together the findings of Priestly, Cavendish and Scheele in his "Traité élémentaire de Chimie"[31] published in 1789.

A table in Lavoisier's book lists some 30 elements, mostly metals, and includes acid radicals, one of which is muriatic — what is now called chloride. Pure chemists are astounded that soil scientists still refer to muriate of potash meaning potassium chloride, one of the major fertilizer salts but this archaic term is written into the U.K. Fertilizer and Feeding Stuffs Act of 1926 and the Regulations of the Agriculture Act 1970.

Lavoisier was a man of many parts: he started a model farm not far from the lovely Chateau at Blois in the Loire Valley and was largely responsible for unifying the weights and measures of France, forerunner of the Metric System. Willy-nilly the scientific world is now committed to the Systéme International d'Unités (S.I. System). Poor Lavoisier was condemned to the guillotine in May, 1794.

While the turmoil of the Napoleonic period ebbed and flowed across Europe, Théodore de Saussure Junior pursued his chemical researches on plants in Calvinist Geneva and published the results in Paris, in 1804[57]. He conclusively proved that green leaves absorb CO_2 from the air in daylight and emit oxygen while the reverse occurs in the dark. So were disproved the earlier notions of van Helmot[7] in Belgium that water is the essential element for plant growth and that of Wallerius[7] at Upsala in Sweden that soil humus is the food of plants.

The 19th Century

I now turn to the Cornishman, Humphrey Davy. His introduction to chemistry was as assistant to a local apothecary but he soon moved to Bristol, studied Lavoiser's book, discovered how inhaling nitrous oxide gas made him laugh and in 1801 was appointed assistant lecturer at the Royal

Institution in London: the next year at the age of 24 he was promoted to Professor! His chief interest was in electrochemistry and thus he discovered the metallic element in potash which he named potassium, besides other alkali and alkaline earth elements.

His fame was such that the Board of Agriculture invited him to deliver a series of eight lectures on Agricultural Chemistry: this he did annually from 1802 to 1812. These were published in 1813[13], the same year in which he appointed a young book-binder to assist him — by name Michael Faraday.

In his fourth lecture Davy drew attention to the importance of the physical properties of soils. His book was translated into German and undobtedly influenced Professor Schübler at the University of Tübingen.

Schübler first published his "Grundsätze der Agricultur-Chemie"[62] (Fundamentals of Agricultural Chemistry)[14] in 1830. Volume 1 deals with the principles of general chemistry and Volume 2 covers soils, fertilizers and agricultural and forest products. The soils section includes nearly 40 pages on the "physical characteristics of soils and methods for their determination"; notably specific gravity, hygroscopic power, water retention, plasticity and heat retention: the forerunner of 20th C. soil physics. A translation of this section from the 1838 edition was printed in the first volume of the Journal of the Royal Agricultural Society of England (1840)[63].

Schübler died at 47 in 1834, but his writing had a pronounced influence on his contemporary Sprengel at Göttingen and on Boussingault in France who, through his wife, had acquired a private estate at Bechelbronn in Alsace.

Sir John Russell[53] rated Boussingault as the founder of modern agricultural chemistry because he was the first to begin careful field experiments on crops which were harvested, weighed and analysed as were samples of soils, manures, fertilizers and feeding stuffs, in order to draw up balance sheets of the inputs and outputs of chemical elements in the soil/plant system in relation to agriculture. He began to publish the results in 1836 and in 1839 was appointed Professor of agricultural and analytical chemistry in Paris, and for some years spent half the year at the Conservatoire and half in Alsace. Boussingault collaborated with Dumas and was able to determine quantitatively the carbon, hydrogen, oxygen and nitrogen contents of his samples. Alas, his experimental farm was lost in 1871 after the German conquest of Alsace. Boussingault collected his experimental data and ideas in a two volume book[8] whose English version of the first edition entitled "Rural economy in its relations with chemistry, physics and meteorology," was published, in the USA, in 1845. Thus we find the first scientific consideration of climatology and atmospheric effects on crops and animals: it was to influence greatly developments in America.

The Liebig Era

Meantime at Giessen in Hesse, Justus von Liebeg, who had established an international reputation for his advances in organic and analytical

chemistry, also turned his attention to soils, crops and animals. He held Davy in high esteem and in 1837 addressed the British Association in Liverpool. In 1840 his most famous book appeared, the English version of which was entitled " Organic chemistry in its application to agriculture and physiology "[33], translated and edited by one of Liebig's many research students, namely Lyon Playfair, who held the Chair of Chemistry at Edinburgh from 1856-69; Browne[7] has pointed out a few errors in Playfair's translation.

Liebig declared " *that humus does not nourish plants by being taken up and assimilated in its unaltered state but by presenting a slow and lasting source of carbonic acid which is absorbed by the roots and is the principal nutrient of young plants at a time when, being destitute of leaves, they are unable to extract food from the atmosphere.*'

Of course he overlooked the store of carbohydrates, etc., in seeds and until 1940 the notion of CO_2 being absorbed by roots would have been generally rejected but now we know through the use of radioactive ^{11}C and ^{14}C that bicarbonate can be assimilated in significant amounts[42] by plant roots.

Liebeg asserted that the nitrogen requirements of crops came from the atmosphere mainly as ammonia carried to the soil in rain. Originally he stated that this supply was insufficient but then changed his mind which brought him into sharp contention with Lawes and Gilbert at Rothamsted; incidentally Gilbert had spent the summer of 1840 in Giessen, contemporary with Playfair, and returned home triumphantly with a Ph.D. after a few weeks work!

Liebig also believed that all the mineral elements in the ash of crops were essential to growth and, rightly, claimed that the bases potash, lime and magnesia as well as phosphoric acid must be restored to the land for the maintenance of fertility in exhausted soils. He advocated treating bone dust with half its weight of sulphuric acid diluted with 3 to 4 parts of water and, after further dilution with 100 parts of water, to sprinkle the fluid over the soil before ploughing: a rather impractical procedure but, unlike Lawes, he did not carry out field experiments.

Because of competition between Britain and the continental countries for bone dust, Liebig let fly one of his best rhetorical outbursts, quoted by Hall[19]:

" *England is robbing all other countries of their fertility. Already in her eagerness for bones, she has turned up the battlefields of Leipsig, and Waterloo, and of the Crimea: already from the catacombs of Sicily she has carried away the skeletons of many successive generations. Annually she removes from the shores of other countries to her own the manurial equivalent of three million and a half of men, whom she takes from us the means of supporting, and squanders down her sewers into the sea. Like a vampire she hangs upon the neck of Europe, nay, of the whole world and sucks the heart blood from nations without a thought of justice towards them, without a shadow of lasting advantage to herself!*"

in fact most of the imports to Britain came from the cattle of South America. As time went on Liebig was obliged to amend his ideas: he concluded his paper[34] in J.R.A.S.E. for 1856, from Munich, with the humbler remarks:

" To myself, in regard to the chemical theory of agriculture, I believe I may apply, without presumption, what Macaulay says of Bacon:—

He was not the maker of that road; he was not the discoverer of that road; he was not the person who first surveyed and mapped that road. But he was the person who first called the public attention to an inexhaustible mine of wealth which had been utterly neglected, and which was accessible by that road alone. By doing so he caused that road, which had previously been trodden only by peasants and higglers, to be frequented by a higher order of travellers."

The Aberdeen Trio of Chemists

Now may I introduce William Gregory, John Shier and John Smith who made their marks while in Aberdeen in the 1840s? My information is gleaned from a fascinating account of " The teaching of chemistry in the Universities of Aberdeen " by the late Professor Alexander Findlay[16].

Gregory graduated M.D. at Edinburgh in 1828 and proceeded to study chemistry under Liebig at Giessen. He was appointed to the Chair of Medicine at King's College, Aberdeen, in May, 1839, which was translated to Medicine and Chemistry in 1840. No doubt to gain a point on Marischal College the splendid house opposite the entrance to King's was provided as the Chemistry Manse! Gregory was a close friend of Liebig: he translated and edited several of his books and the mutual admiration seems to have been reciprocated for in a letter to Berzelius after his tour of Britain Liebig wrote:

" England is not the Land of Science, only of widely practised dilettantism: the chemists are ashamed to call themselves such because apothecaries, who are looked down upon, have captured this name for themselves. Scientifically, Graham is the most esteemed exception, he is a splendid fellow, so also is Gregory who succeeded him at Glasgow."

Gregory stayed only five years in Aberdeen and then moved to the Chair of Chemistry at Edinburgh.

Up in Marischal College, Professor Clark had gained fame through his soap titration method for determining the hardness of water and its treatment with lime, but he was a sick man and from 1844 the work of the Department was mostly carried out by deputies. The first was John Shier who had included chemistry, geology and natural science in his M.A. degree course before he moved to Edinburgh and trained in practical chemistry under Dr Boswell Reid, whose text book on " Elements of chemistry — theoretical and practical "[44] included detailed descriptions of some 45 elements and their compounds: it is interesting to note that aluminum is spelt as it is today in America. A copy of the 1839 edition

was acquired by Lawes at Rothamsted and is still held in the library there. The chapter on phosphorus gives details of how to treat burnt bones with sulphuric acid to obtain superphosphate and also phosphoric acids and phosphorus.

Shier had returned to Aberdeen in 1835 and was such a good teacher that he attracted students away from Clark so that some friction arose. Then, in 1840, in addition to his chemistry duties he was appointed the first Fordyce Lecturer in Agriculture to give 12 public lectures on Chemistry, Natural History and Agriculture annually under a bequest from Sir William Fordyce, Rector of Marischal College, 1790-91.

In 1844 Shier published a new edition of Davy's book[64] to which he added copious notes of his own incorporating the results of numerous researches by Liebig, Boussingault and others besides himself, together with practical instruction for analysing soils. Shier stated that "*bone dust is much used all over Scotland but in no district so universally as in Aberdeenshire and in adjoining counties as a supplement to farmyard manure for growing turnips. During the year 1840-41, 4355½ tons of bone dust were imported into Aberdeen from foreign parts.*" He goes on to describe his method for treating bone dust with strong sulphuric acid (Brown Oil of Vitriol) following the principle of Reid, instead of the diluted acid procedure of Liebig. Thus Shier's method closely resembled that employed by Lawes which proved so successful in field trials that he patented it in 1842. Whether Shier and Lawes knew what each other were doing, we shall never know, but certainly both possessed Reid's textbook and Lawes spent many summer holidays deer stalking and salmon fishing in Scotland.

The early volumes of the Journal of the Royal Agricultural Society abound in reports of trials with bones, guano, saltpetre and new chemical fertilizers, including ammonium sulphate and Chilean nitrate of soda. Volume 5, 1844, includes a report from the Duke of Richmond[47], President of the Society, of experiments at his Home Farm, Gordon Castle, Morayshire, to compare the effects of bone dust with and without sulphuric acid treatment on the yields of turnips and barley. Also one of his tenants, Mr Wagstaff[71] at Westerton Farm near Huntly, reported favourably on the improved growth of turnips in 1843 when a bone dust "liquid" prepared, much as Liebig had recommended, was applied along the turnip drills: an early example of fertilizer placement.

Surely John Shier must have known of these trials. However, having been awarded the LL.D. in 1845 he was appointed to investigate the agricultural resources of British Guiana and died there nine years later.

In 1847 John Smith, M.D., son of a blacksmith at Peterculter, was appointed to assist Clark and to be Fordyce Lecturer as Shier had been. Obviously very competent, in 1852 he was appointed as the first Professor of Chemistry and Experimental Physics at the new University of Sydney in Australia. My main reason for including him is his very interesting paper in the Quarterly Journal of the Chemical Society for 1852 "On the composition of the waters of the Dee and Don, at Aberdeen, with an investiga-

tion into the action of Dee water on lead pipes and cisterns "[65]. His data show a distinctly higher base content of the Don water and point to the dangers of lead poisoning from the Dee water held in lead lined cisterns which abounded in the houses of Aberdeen. He reveals a good understanding of the differences in geology between the more abundant granitic rocks of the Dee catchment and the more basic rocks, including serpentine of the Don catchment. Recent University studies of the waters of Glen Dye[45, 46] and Glenbuchat[11] have verified and greatly extended Smith's original concept.

Lawes' Enterprise

Meantime in the 1830s, John Bennet Lawes, heir to Rothamsted Manor, while a student at Brasenose College, Oxford, developed an interest in chemistry and attended lectures by Professor Daubeny, but he did not complete his degree because of the need to manage the estate for his widowed mother. He found that crushed bones had little benefit for turnips on the calcareous Rothamsted soil and in 1839 began field experiments with his superphosphate.

Lawes sought a chemist to assist with crop and soil experimental work so that he could attend to his business venture of manufacturing superphosphate and his animal feeding trials. The man he appointed was Henry Gilbert who had studied at Glasgow, then University College, London, under Graham and finally at Giessen.

So were started the classical field experiments, beginning in 1843 with the famous fertilizer strip plots on wheat in Broadbalk field: no manure, farmyard manure, mineral N, NP, NPK treatments. These are still being conducted with some modification of the original design. The partnership continued until Lawes' death in 1900, marred only by friction between Gilbert and a younger assistant recruited temporarily by Lawes named Robert Warington, Junior[56]. Personality clashes can arise in the best of establishments! but there is no trace of acrimony in the obituaries of both men compiled by Warington[73]. Full details of the first 50 years of Rothamsted experiments were published by Hall in 1905[18].

Thomas Way

Returning to 1843: a young assistant to the famous Professor Graham at University College, London, moved to Oxford as assistant to Professor Daubeny. His name was John Thomas Way and his duties were to analyse crop plants as was being done in Liebig's laboratory in Giessen. However, after three years he became Professor of Chemistry at the flourishing Royal Agricultural College, Cirencester in Gloucestershire but only for two years. While there, Way was told by Henry Thompson, a founder member of the Royal Agricultural Society of England, of experiments he had conducted at his home, Kirby Hall near York, in 1845, on the absorption of ammonia by a sandy loam soil when treated with dilute solutions of ammonium bicarbonate or sulphate and of the corresponding displacement of calcium from the soil into solution.

Way recognised the significance of this observation and carried out over 90 laboratory experiments which are detailed in the J.R.A.S.E. for 1850[74]. Thompson's lesser investigations are also recorded in a separate paper[67], each man cordially acknowledging the importance of the other's findings. So was discovered the phenomenon of cation exchange, though to Way ammonium, potassium, sodium, calcium and magnesium were but base radicals and chloride, nitrate and sulphate acid radicals: although Faraday had demonstrated in 1833 that one part of an electrolyte moves to the anode and the other to the cathode, the physio-chemical concept of charged anions and cations in solution had to wait until Svante Arrhenius[1] published his famous work in 1887. Incidentally, thirty years later his nephew, Olaf Arrhenius[2], pioneered the study of crop tolerance to soil acidity in Sweden.

The Royal Agricultural Society appointed Way as its first consulting chemist in 1848 so he moved from Cirencester to 15 Welbeck Street, Cavendish Square, in London. Naturally, his major publications of the period were in the Society's journal; the second paper[75] on the absorptive power of soils contains a good summary of the first and then reports on the synthesis of double silicates of aluminium with bases which possessed exchange properties corresponding roughly to the synthetic allophane and zeolites of more recent times. A third paper[77] dealt with the effect of lime on the absorptive power of soils. Way was convinced that clays were the sole seat of base exchange properties and discounted the organic components of soil.

The next significant works of Way appeared in 1855 on the use of town sewage as manure[76] and in 1856 on the composition of water of land drainage and of rain, the samples of rain water being provided by Lawes from Rothmsted in 1855 and 56. His data[78, 79] clearly showed that the concentration of ammonia was less in drainage water than in rain while from fertile soils the concentration of nitrate was much higher in the drainage than in rain: the first report[33] has an appendix giving details of Way's analytical procedures. Thus did Way rediscover in a quantitative manner the formation of nitrate in fertile soils, but he frankly admitted he did not understand the mechanism. However his finding prompted Lawes, Gilbert and Warrington to study the subject in depth.

Way was very industrious and practical: he introduced the unit system of calculating the relative values of nutrient elements in fertilizers and manures, but the Minutes of the R.A.S.E. Council reveal that relationships with his governing Chemical Committee were sometimes strained and in 1857 he resigned. He and Lawes were appointed members of the Royal Commission "*to inquire into the best mode of distributing the sewage of towns and applying it to beneficial and profitable uses*"[6]. The two men conducted important experiments on the irrigation of land with sewage[32] which led to the establishment of "sewage farms". Way became much involved in the problems of London's sewage until he died in 1884 aged 64.

The late Dr Crowther urged soil scientists to honour the memory of Way by giving his name to the meq unit of cation exchange capacity, but universal support for the idea was not forthcoming.

Biological Investigations

In the latter half of the 19th C. biologists joined hands with chemists in the advancement of soil studies. Sachs in Germany laid the foundations of modern plant physiology: his striking experiment in which the pattern of the fine root system became etched on the polished face of a marble slab embedded in the soil within a pot was thought to demonstrate the excretion of acids by root hairs. It was on this hypothesis that, in 1894, Dyer chose a one per cent solution of citric acid[14] for extracting the so-called available phosphate and potassium from soils since it corresponded approximately with the titratable acidity of the root sap in many crop and weed species. When applied to soils from the plots of the Rothamsted Broadbalk wheat field, the method certainly showed distinct differences corresponding with manurial treatments[15] and subsequently it was widely used in the earlier part of the 20th C. for advisory purposes.

Sachs and his contemporary Knop[29] developed water culture techniques for studying the effects of mineral elements on plant growth listed by Liebig and demonstrated that, without an adequate supply of iron, leaves soon became chlorotic. In 1885 Knop[30] established that, whereas chromium oxide was too insoluble to be toxic, dilute chromic and particularly chromate salts were highly toxic to maize. Of course, with modern means of purifying chemicals and sensitive analytical methods, 20th C. workers have been able to study the role of many elements in great detail.

In 1886, at a meeting in Halle, attended by Gilbert, Hellriegel and Wilfarth[21] made known the results of their experiments with Legumes and non-Legume plants grown in sand culture which showed conclusively that, when Legumes developed nodules on their roots, they obtained adequate nitrogen for growth and these nodules were colonies of symbiotic nitrogen-fixing bacteria. This brought meaning to some of Rothamsted's puzzling results and stimulated research there. Nearly a century later this topic is of increasing global significance with some very sophisticated research in progress by the A.R.C. unit at the University of Sussex and at other centres; nitrogen being the dominant element needed for high yields.

Although Warington came very near to understanding the mechanism of nitrate accumulation in soils, it remained for Winogradsky[82] to identify by very elegant culture studies the specific Nitrosomonas and Nitrobacter bacteria responsible for the two step oxidation of ammonium through nitrite to nitrate. This remarkable man was born in Kiev in 1856, heir to his father's well-ordered estate. His microbiological studies began in St Petersburg, but the resources there did not satisfy him so he moved to Strasbourg and undertook pioneering work on the autotrophic bacteria responsible for iron and sulphur transformations. He moved to Zurich in 1888 and within two years by using media without added organic substances had essentially solved the whole problem, his results being published in the Annals of the Pasteur Institute[40]. Although invited by Pasteur to join him in Paris, Winogradsky returned to St Petersburg as chief of a medical microbiology laboratory and there began a study of non-symbiotic nitrogen fixing

organisms. He isolated Clostridium[53] from soil, but it remained for Beijerinck[5] to isolate the aerobic Azotobacter. His health deteriorated and in 1905 at the time of the Russo-Japanese war he returned to his estates away from laboratory research. The Bolshevik revolution forced him to flee Russia for Switzerland and there he accepted a second opportunity to join the Pasteur Institute with special facilities provided at Brie some 20 miles from Paris. Here, after a gap of 17 years, he began the direct microscopic examination of soil, with further studies of the nitrifying bacteria and decomposition of cellulose. The German invasion of Paris in 1940 forced him into retirement again but he lived to 97. I strongly recommend a reading of the masterly tribute by Waksman[72] written in 1946 to mark Winogradsky's 80th birthday.

Time forbids a detailed account of Waksman himself who, being Jewish, emigrated from Russia to the U.S.A. at the age of 22 in 1910. His remarkable career in the study of soil humus and antibiotics, particularly streptomycin, culminated in the award of a Nobel prize in 1952[66].

I would, however, like to refer at this point to recent work by Dr Döbereiner and her associates in Brazil. At the International Congress of Soil Science in New Delhi earlier this year I listened intently to her paper[6] on the association of Azospirillum and other diazotrophs with tropical Gramineae. Azospirillum colonises cells in the root cortex and consumes organic substrates from various host plants in order to fix molecular nitrogen. One slide showed an infection in the xylem cells of maize roots where malic acid appeared to be the principal carbon source.

Russian and American geologists join in

Vasilii Dokuchaev was born near Smolensk and attended the Theological Academy in St Petersburgh for a year before he turned to natural science and specialized in mineralogy and geology. He became curator of the University geological laboratory and led many expeditions to study soils. His famous book " Russian Chernozem " (Black Earth) appeared in 1883 and he died in 1903 at the age of 57. His two assistants, Sibertzev and Glinka were inspired to achieve major developments in the study of soils as natural bodies resulting from the interactions of rock types, weathering processes, climatic conditions and vegetational zoning[26]. The North-South succession of features from the Arctic Tundra to the Black Sea is very striking and it was my privilege to cover much of the " Dukuchaev trail " with John Muir and others in 1964.

In many respects Eugene Hilgard is the father figure of soil science in the U.S.A. He was taken by his parents when three years old, in 1836, from Austria to America but returned to Europe to study at Heidelberg. He then began geological work in Mississippi, being appointed State mineralogist in 1859; and quickly published a report on the Geology and Agriculture of that State in 1860. He moved to the University of California in 1874 and died there in 1916. In some ways Hilgard's pedological studies preceded the Russian school but he had particular regard to agri-

cultural development in California. His book "Soils"[24], published in 1906, has become a classic and contrasts markedly with Hall's "The Soil" which first appeared in 1903.

The Exponential 20th Century

In 1890 the Treasury found itself with a rare surplus of funds following a substantial increase in taxes on whisky and spirits. Fortunately these were diverted through the Local Taxation Act (Customs and Excise) to support technical education, including agriculture. Some of this "whisky" money accrued to centres of higher agricultural education.

In 1891 a Lancastrian, Daniel Hall, who had graduated with Class I honours in Chemistry from Oxford, after several years of school teaching, was appointed to develop University extension courses in Science in South-East England. He conceived the idea of starting an agricultural college and, the County Councils of Surrey and Kent having backed his plan, Wye College was opened in 1894 with Hall as Principal. It flourished and when, in 1900, it was incorporated as a College of London University, E. J. Russell was appointed to the Chemistry lectureship. In his delightful autobiography "The Land Called Me" (1956)[55] Russell recounts the circumstances leading to his appointment: as the son of a Unitarian Missionary he had inclinations to follow his father and entered the Presbyterian College of Carmarthen on a very modest scholarship. After one year he moved to Aberystwyth to study science for two years and finally completed a London University first class honours in Chemistry at Owens College, Manchester, under Perkin and Roscoe in 1896. Despite significant progress in pure chemistry research, Russell was keen to apply for the post at Wye. Perkin was not encouraging but he said to young Russell: *"If you really want the post you must turn up at the interview in a frock coat and a tall hat, otherwise the Agricultural Committee will not look at you."* When Russell got back to Manchester in triumph, Perkin mused: *"It was the tall hat and frock coat that did it!"*

Hall had started a survey of the Agriculture and Soils of Surrey and Kent, but he left Wye in February, 1902, to become Director of Rothamsted despite the decrepit state of its chemistry laboratory: Gilbert's eyesight had been poor. Following a grant of £10,000 from the Goldsmith's Company in 1907, Dr Russell joined Hall. Together they completed the survey of the agriculture and soils of Kent and Surrey plus Sussex. Many of the mechanical analyses carried out at Wye were repeated at Rothamsted using a revised method and the report was published in 1911[20]. It remains a classic because in the unglaciated Wealden area the sedimentary rocks and drift deposits dominate the soil properties, It contains a delightful poem about the Sussex downs and the oxen plough teams which the Treasury and the Board of Agriculture objected to as a waste of space, but Hall persisted and won his case.

In 1909 another financial stimulus was provided by Lloyd George's Development Fund of £3 million over five years for scientific advancement of afforestation, agriculture and fisheries. Hall became one of eight Com-

missioners and was succeeded by Russell as Director of Rothamsted in 1912.

This fund provided for the establishment of several agricultural research institutes and helped to boost developments at Aberdeen where James Hendrick became, in 1912, the first Strathcona-Fordyce Professor of Agriculture, having previously been a lecturer in agricultural chemistry successively at the Royal Agricultural College, the West of Scotland College and, from 1896, the North of Scotland College. He had a vision of two research stations being established in Aberdeen and in 1913 William Ogg was appointed assistant to undertake a study of the soils of Craibstone: a year later John Boyd Orr joined him in the basement laboratory under the front of Marischal College to begin studies in animal nutrition. Both men left for war service: Orr returned as Director of the Rowett Institute in 1920, but Hendrick had to wait until 1930 for the fulfilment of his dream with the establishment of the Macaulay Institute.

Professor Hendrick wrote an introductory book on the "Farmer's raw materials"[23]: I never met him but through a chance conversation with Mr Petrie of the School of Agriculture I learnt that Hendrick's laboratory attendant, John Davidson, was still living in Broomhill Road. This grand old man of 95 was able to tell me of his appointment in 1912 and of his visits to Craibstone to collect samples of drainage water from Hendrick's lysimeters for Mr Welch to analyse.

Three drain gauges or lysimeters had been established at Rothamsted in 1870, each having a surface area of 1/1000 acre and containing blocks of fallow soil respectively 20, 40 and 60 inches deep[18]; and in the summer of 1914 Hendrick recruited a Durham miner to excavate under three blocks of soil of the same size at Craibstone. Difficulties arose because of leaks in the side wall joints and the wartime conditions so the rotational cropping and manuring experiments were delayed until 1919: these were continued to World War II and provided valuable data on the water balance, nutrient losses by crop removal and drainage, and weathering products of soil minerals leached into the drainage water. I was fortunate to see these historic lysimeters, sadly in disuse, before they were destroyed in 1959 to make way for a new farm barn. Details of their construction were reported by Hendrick in 1921[22].

Advances in physical science

The turn of the century before World War I witnessed developments in fundamental physical science which were to have profound influences on soil science. I remember as an undergraduate at Reading in 1937 watching with great respect a tottering little man in the academic procession to receive an honorary D.Sc.: that was Sir J. J. Thomson whose work at Cambridge confirmed experimentally in 1897 the existence of electrons around atomic nuclei. Two years previously Röntgen had discovered X-rays emitted from a metal target and in 1896 Becquerel reported the natural radioactivity of uranium salts.

In 1910 the Danish chemist Sörensen published from the Carlsberg Institute in Copenhagen his theoretical considerations which led to the pH

scale of hydrogen ion activity. Today " top of the form " competitors are expected to know about pH values for defining acidity and alkalinity!

In 1913 W. H. Bragg and his son W. L. published their first joint paper which founded crystal analysis by means of X-ray diffraction studies: C. S. Ross reported X-ray evidence of crystallinity in soil clays to the first International Congress in Soil Science at Washington, U.S.A., in 1928, which was attended by Ogg, Hendrick, Russell and G. W. Robinson.

Extension of soil science in Britain

For me Professor Robinson is certainly a prominent marker; so far as I know the only Soil Scientist outwith Rothamsted to be elected F.R.S. He was born at Wolverhampton in 1885 and his mother came of Welsh speaking stock. He graduated with distinction at Cambridge in 1909 and chose to follow post-graduate studies on soil. Professor Wood directed him to a survey in his native Shropshire along the lines of that conducted by Hall and Russell: it was published by the Shropshire Education Committee[48] in 1913, a year after he was appointed Advisory Agricultural Chemist for North Wales based at University College, Bangor. At Cambridge he had associated with a group of Welsh speaking students and no doubt this was as much an advantage to him at his interview as was Russell's frock coat at Wye.

Robinson was a great linguist in European languages and a genial churchman with a flair both for field soil studies and for laboratory innovation. Independently of German and American investigators he devised the elegant pipette procedure for sampling the fine particles in soil suspensions following peroxide treatment of soils to destroy organic matter before dispersion[51]. It was largely the result of his efforts that the International method of particle size analysis using the Atterberg scale was adopted.

At a symposium on " Base Exchange in Soils " held by the Faraday Society in 1924 Robinson, in collaboration with Rice Williams[52], Dr E. G. Williams' brother, emphasized the importance of exchangeable calcium in dealing with the practical problems of soil acidity.

G.W.[54], as he was affectionately known, began to organize Soil Survey work in Wales soon after World War I and wrote a masterly paper for the Geological Magazine in 1924 on " Pedology as a branch of geology "[49] in which he propounded for the first time in the English language the use of the term Pedology to cover the more esoteric aspects of soil science. It appears that neither the geologists nor the agricultural scientists of the day were much impressed. His outstanding book published in 1932 entitled " Soils, their origin, constitution and classification," was subtitled "An introduction to pedology "[50]. Along with the seventh edition of Russell's book[53] it was my vade-mecum in pre-war days.

Although the Russian, Tulaikoff[70], while working with Hilgard in California, had published a paper in English on the genetic classification of soils in the 1909 issue of the Journal of Agricultural Science, little attention seems to have been given to it in Britain except by Robinson and Ogg: it

remained for Marbut's[35] translation from the German in 1927 of Glinka's work to achieve the necessary impetus for a proper appreciation of the Russian system of soil profile description and classification.

During my final honours year at Reading I was initiated in the intricacies of soil profile studies by Dr Frances Kay (Mrs Moore) in the area around Harwell, where the Atomic Energy Research Station now stands. She graduated in Horticulture at Reading in 1930 and was recruited for soil survey work by my old mentor, Professor Neville. She recently wrote me from Wales a scintillating account of those early days of soil survey on a bicycle. Her Soil Survey of the Vale of the White Horse[27] is the classic forerunner of those which have appeared in the post-war years.

Fig. 3.

Soil Survey Group, Berkshire, 1935 (from left to right): 1, Mr Dines, Geological Survey; 2, Prof. Hardy, Trinidad; 3, Prof. Robinson, Bangor; 4, Dr Hart, Macaulay Institute; 5, Mr Paterson, Dartington Hall; 6, Dr Marbut, USDA Soil Survey Chief; 7, Dr Shaw, California; 8, Dr Frances Kay, Reading; 9, Unknown; 10, Dr Ellis, Manitoba; 11, Prof. Neville, Reading; 12, Dr Muir, Macaulay Institute; 13, Dr Kellogg, Chief after Marbut.

Fig. 3 is a photograph taken in 1935 by Dr Osmond during an unofficial field trip from Oxford at the time of the Third International Congress. It has great historic interest since several of the individuals contributed much to the advance of soil survey and classification.

Marbut left Oxford the next day for China and died at Harbin. Muir translated Polynov's classic work " The Cycle of Weathering "[43]. Frances Kay tells how she saw the colours of the aurora borealis one evening and dreamed of colours for soil maps since the existing geological colours were inappropriate. She was co-opted to the map colouring sub-committee of the Soil Correlation Committee and exhibited a map coloured by her mother,

pink for podzols and blue for gley soils. Her enthusiasm won the day with backing from Dr Muir. Dr Glentworth remembers well the gathering at Crieff with Frances present, a year or two before the outbreak of War.

The patient achievements of the Soil Survey staff in Scotland are well represented by the maps of the N.E. showing the pattern of distribution of soil types in relation to the nature of the major geological formations, even though glacial till either mixed with or overlying deeply weathered rock comprises most of the parent material.

I sat my finals at Reading in the summer of 1938 and was interviewed for a Ministry of Agriculture postgraduate studentship to work at Rothamsted by Sir Daniel Hall and Sir John Russell. The other candidate was George Cooke and clearly Hall and Russell recognised the potential of a future F.R.S. in him rather than me!

However, in September at the time of the Munich crisis, I was interviewed for the post at Wye College as assistant to the Ministry of Agriculture Advisory Chemist for the S.E. counties: unlike Russell in 1900 I did not wear a frock coat, but I got the job and spent five very formative years there, four of them under wartime conditions, virtually in the footsteps of Hall and Russell.

My chief, D. Pizer, encouraged me in developing a rapid semi-automatic system of soil testing to cope with the urgent demand and I became familiar with analytical studies at the Macaulay Institute by Dr Williams and Dr Stewart[80], published in 1941.

The shelves of my laboratory were stacked with crop protection materials accumulated by Dr Hubert Martin before he went to Long Ashton and thus I realised the increasing importance of this subject in the area of intensive agriculture and horticulture.

Sir John Russell was succeeded as Director of Rothamsted by Dr Ogg in 1943, the centenary of the Experimental Station. My last two markers, who served under these Directors, are Dr R. K. Schofield and Dr H. L. Penman, F.R.S.

Robert Kenworthy Schofield joined the Physics Department at Rothamsted in 1928 from Durham University. Having studied the physical retention of water in soils in terms of the difference between the free energy of film water and bulk water, he suggested the pF scale at the Oxford Congress in 1935[58]. pF is now as much part of soil lingua-franca as pH. His elegant work on the effect of pH on electric charges carried by clay particles appeared in 1959 as the very first paper in the Journal of Soil Science[59] and thereafter in collaboration with Asyling and with A. W. Taylor he laid the foundation of cation and anion activity/diffusion studies in soils[60, 61]. In 1956 he moved to Oxford as Reader in Soil Science and died in 1962 while President of the Society.

Howard Penman succeeded Schofield as Head of Physics at Rothamsted, having joined the Department in 1937.

The first number of J.S.S. is certainly a vintage one containing, besides Schofield's paper, Glentworth and Dion's "The association of hydrologic

sequence in soils of the podzolic zone in N.E. Scotland " and MacEwan's " The recording and interpretation of X-ray diagrams of clays," but it is Penman's contribution on " The dependence of transpiration on weather and soil conditions "[39] which merits special attention today.

From basic physical principles Penman had previously devised formulae[38] for calculating with reasonable accuracy the rate of evaporation of water from an open water surface and from cropped soil using standard meteorological data of that time, namely mean air temperature, relative humidity, windspeed and hours of bright sunshine[40].

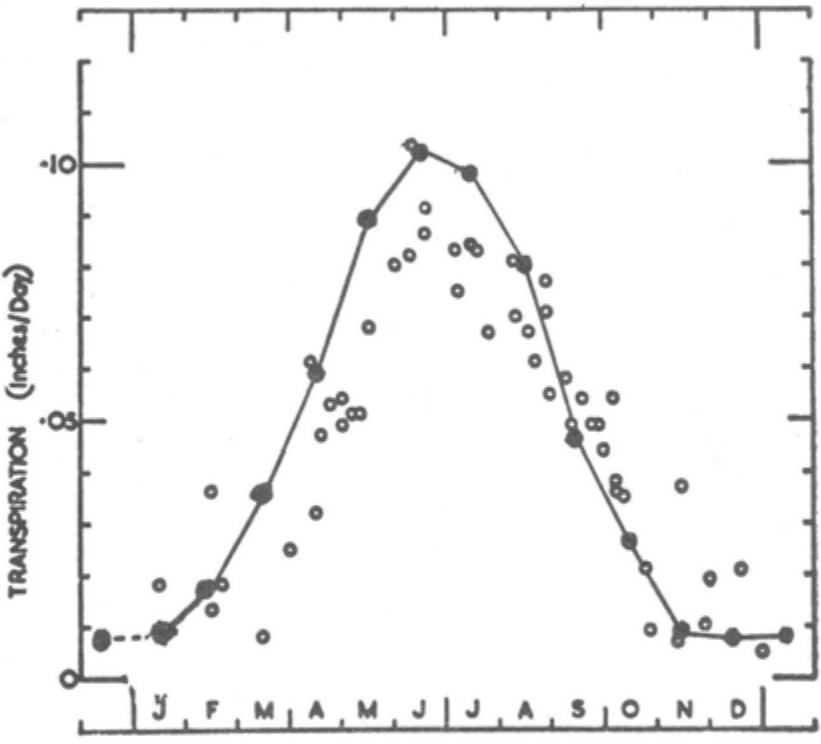

Fig. 4.
Estimated means (●) and observed (o) transpiration rates from Craibstone lysimeter for 6 years of pasture.

Fig. 4 shows the calculated and actual transpiration from the grass-covered Lysimeter 3 at Craibstone using meteorological data from Dyce over a six-year period[39].

The first practical outcome of Penman's fundamental work was to make available local estimates of the frequency of irrigation need. Given a rain gauge in a field or on a farm, with access to daily computerised meterologi-

cal data, individual farmers can now obtain estimates of water deficits and irrigate as needed. The global consequences are tremendous.

The interaction effects of water and nitrogen supplies on the growth of crops at Woburn illustrate the impact of Penman's field experiments[41].

The shape of farms to come?

In the summer of 1981, Mr Rennie, a Midlothian farmer, harvested 14 tonnes/ha of wheat at 16% moisture content from a 17·5 ha field. As Sir Leslie Fowden has stated[17], such yields are near what is considered the maximum possible in open field under favourable weather conditions.

Such achievements have resulted from the combined benefits of good cultivation techniques, fertilizer and crop protection treatments and particularly the success of plant breeders, yet in many parts of the world grain yields are frequently below one t/ha.

There has long been a debate about the merits of rotation cropping with livestock production versus intensive arable cropping with little or no livestock. The dangers of pest, disease and weed buildups in continuous monoculture systems have been stressed, yet curiously Nature has a way of adjusting.

A fascinating example in a Canadian publication on "The nematode destroying fungi" by Barron[4] shows a nematode caught in a fungal noose and also a nematode being devoured by penetrating hyphae. Dr Kerry[28] at Rothamsted tells me that the populations of nematodes in cereal fields throughout Europe and in soya bean fields of the U.S.A. have declined from their maxima in recent years — presumably largely through the activities of specific fungi, some of which set traps and others have spores that penetrate the nematode. Continuous cropping may not be so disastrous as some have expected if the soil can be maintained in good physical condition.

In an article on "The mechanical farm of the future," published in Chemistry and Industry[36], John Matthews of The National Institute of Agricultural Engineering envisages an extension of the "tramline system" for cereal and row crops. He shows an artist's impression of a "gantry system" with tracks permanently constructed over drain/irrigation lines about 20 metres apart. The gantry could carry out every operation from cultivation to harvest without mechanical compaction of the soil between tracks. Is this science fiction? If technically successful, would it be generally acceptable to the countryside lobby for widespread adoption in the flatter, fertile lowlands of Britain?

Within a glass or plastic cover the environment of high-value crops can be manipulated better than in the open. Professor Wittwer in Michigan has shown[84] how yields of lettuce were boosted by trebling the CO_2 content of the air in commercial size glasshouses. He holds the view that fears of the consequences of rising CO_2 contents in the global atmosphere are largely unjustified because terrestial plants and the oceans would automatically buffer the level.

Time does not allow me to digress on the exciting possibilities of monitoring local and global crop growth by remote sensing from "Landsat" satellites. Dr Stove and his colleagues here at MISR are in the forefront of developments in the interpretation of ground features from spectral images.

Acknowledgements

In closing may I express my thanks to all who have helped in any way by providing information or slides. May I also convey my gratitude to so many of you for many kindnesses over the past quarter of a century. If in the 21st Century someone updates the boundary markers of Soil Science, I guess there may well be one or two of those listening to me today among them.

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APPENDIX II

VISITS ABROAD — 1981-82

	Place/Event	*Lectures*	*Date*	*Financed by*
1. G. Anderson	Bayreuth (FRG) Symposium on transfer processes	1	January	Univ., Bayreuth
2. G. Anderson	New Delhi (India) 12th International Congress of Soil Science	—	February	DAFS
3. B. W. Bache	Uppsala (Sweden) Acid Rain Symposium	—	February	Swedish Govt.
4. B. W. Bache	Stockholm (Sweden) Environment '82	1	July	Organisers
5. B. W. Bache	Copenhagen (Denmark) Aquatic Environment Conference	1	August	Organisers
6. J. R. Bacon	Vienna (Austria) 9th International Mass Spectrometry Conference	1	September	DAFS
7. M. L. Berrow	EEC Community Bureau of Reference Meeting on problems of atomic absorption spectrometry for the determination of chromium in soils and sludges.	—	November	EEC
8. J. S. Bibby	Ottawa / Hull / Guelph / Edmonton* (Canada) Research Stations	1*	July	DAFS
9. J. M. Bracewell	Colorado (USA) 5th International Symposium on Pyrolysis, School of Mines, U.S. Geol. Survey	2	September	DAFS
10. M. V. Cheshire	Vancouver (Canada) 11th International Carbohydrate Symposium	2	September	DAFS
11. M. V. Cheshire	Berlin (FRG) Workshop on Biodegradation Testing in Soils, Department of the Environment	—	December	Organisers
12. V. C. Farmer	New Delhi (India) 12th International Congress of Soil Science	1	February	DAFS
13. V. C. Farmer	Fukuoka (Japan) Annual Conference Japan Society of Soil Science	1	April	JSPS
14. V. C. Farmer	Various Centres (Japan)—JSPS Fellowship	7	March/April	JSPS
15. V. C. Farmer	Various Centres (Australia)—CSIRO Scholarship	10	May/June	CSIRO
16. V. C. Farmer	Various Centres (New Zealand) N.Z. Soil Science Lectureship	7	June/July	N.Z Soil Sci. and DAFS
17. V. C. Farmer	Various Centres (Canada) Canadian Soil Science Lectureship	14	July/August	Can. Soc. Soil Sci. DAFS and NATO
18. B. A. Goodman	Stanford (USA) Conf. Mag. Res. Biol, Systems	2	April/December	Fellowship and Civil Service—Nuffield and Leverhume Fellowship
19. B. A. Goodman	Hawaii (USA) American Clay Minerals Conference	5		
20. B. A. Goodman	Richmond/Lake Habtu (USA) Chevron Laboratories	3		
21. B. A. Goodman	Urbana, Illinois (USA) Study Leave	—		
22. R. C. Mackenzie	Amman (Jordan) University of Jordan	5	March	British Council
23. R. C. Mackenzie	Riyadh (Saudi Arabia) University of Riyadh	1	May	Riyadh Univ.

		Place/Event	Lectures	Date	Financed by
24.	R. C. Mackenzie	Ontario (Canada) 7th International Conference on Thermal Analysis	1	August	DAFS and Self
25.	W. J. McHardy	Poitiers (France) International Working Group Sub Microscopy Undisturbed Soils	1	November (1981)	DAFS
26.	H. G. Miller	Ghent (Belgium) IEA Forest Energy Meeting	1	April	IEA
27.	H. G. Miller	Göttingen (FRG) Workshop, Air Pollution	1	May	Umweltbundesaamt (Berlin)
28.	H. G. Miller	Seattle (USA) IUFRO Symposium	1	August	Conf. Organisers and DAFS
29.	H. G. Miller	Uppsala (Sweden) Reviewing effects of management practices on the long-term fertility of forests	—	December (1982)	Swedish Univ. of Agriculture
30.	P. F. S. Ritchie	Frascati (Italy) Landsat-4 Workshop on System Sstatus and European Data Requirements	—	November (1982)	Self
31.	R. A. Robertson	Helsinki (Finland) Meeting on Peat Technology	—	February	Self
32.	R. A. Robertson	Ivalo (Finland) Executive: International Peat Society	—	May	Self/IPS
33.	R. A. Robertson	Minsk (USSR) Symposium—International Peat Society	—	September	DAFS
34.	N. M. Scott	Georgia/Alabama (USA) Study Tour Sulphur Research	1	September	DAFS
35.	C. A. Shand	Munich (FGR) 2nd International Workshop — Trace Elements in Biology and Medicine	1	April	Scottish Hospital Endowment Res. Tr.
36.	G. P. Sparling	Boston (USA) 13th International Congress on Microbiology and Fort Collins (USA) University of Colorado*	1*	August	DAFS
37.	G. C. Stove	Munich (FRG) IEEE International Geosci. and Remote Sensing Symposium	—	June	DAFS
38.	A. M. Ure	Brussels (Belgium) EEC Assessment of Inter-laboratory certification analysis for proposed reference standards (sludges and soils) issued by Comm. Bureau of Reference	—	September	EEC
39.	A. M. Ure	Utrecht (Holland) IUPAC Meeting of Commission V.4 —Spectrochemical and other Optical Procedures for Analysis	1	October	IUPAC
40.	A. M. Ure	Oslo (Norway) Norwegian Chemical Society's National seminar in atomic absorption/emission spectroscopy and visit to Geological Survey, Trondheim	1	November (1982)	Central Institute for Industrial Research, Oslo
41.	D. Vaughan	Athens (Greece) Meeting of Federated European Biochemical Societies	—	April	DAFS
42.	T. S. West	The Hague (Netherlands) Executive Committee, IUPAC	—	May	IUPAC
43.	T. S. West	Prague (Czechoslovakia) Bureau and Executive Committee, IUPAC	—	September	IUPAC

APPENDIX III

LECTURES GIVEN IN THE U.K. BY MEMBERS OF STAFF

	Place	*Event*	*Date*
Department of Mineral Soils			
A. C. Birnie	Compton	ARS Conf. Elect. Microscopy	March/April
W. J. McHardy	Compton	ARS Conf. Elect. Microscopy	March/April
	Edinburgh	Mineralog. Soc. Clay Min. Group	April
R. C. Mackenzie	London	ICTA Nomenclature Committee	March
	Hatfield	7th Thermal Anal. School	April
E. Paterson	London	Mineralog. Soc. Clay Min. Group	November, 1981
M. J. Wilson	London	Mineralog. Soc. Clay Min. Group	November, 1981
	London	4th Conference X-ray Pdr. Diffract.	September
Department of Peat and Forest Soils			
R. V. Birnie	Glasgow	Univy. Dept. of Geog.	November, 1981
	Aberdeen	Univy. Geog. Soc.	November, 1981
	London	Ann. Conf. Remote Sens. Soc.	December, 1981
	Inverness	HIDB	July
	Liverpool	Brit. Assoc. Advance Sci.	August
	Aberdeen	Remote Sens. Course Land Cover Mapping (3)	September
P. D. Hulme	Southampton	Brit. Ecol. Soc. Mires Res. Group	December, 1981
H. G. Miller	Windermere	GRAWS Meeting on Forests and Acidification	October, 1981
	Edinburgh	EFG Forest Nutrition Course	November, 1981
	Edinburgh	Forestry Comm. Res. Seminar	January
	Aberdeen	University Seminar	January
	London	UCL Workshop on Priorities in Forest Res.	March
	Chester	FC Nursery Foresters Meeting	September
	Edinburgh	Edinburgh Bot. Soc. Symp. on Birch	September
P. F. S. Ritchie	Monks Wood	ITE Symp. on Ecol. Mapping from Air, Ground and Space	November, 1981
	Aberdeen	Remote Sens. Course for Land Cover Mapping (2)	September
R. A. Robertson	Gorebridge	DAFS Lands Branch Conf.	November, 1981
G. C. Stove	Aberdeen	Remote Sens. Soc. Seminar	October, 1981
	Aberdeen	Brit. Cartog. Soc.	October, 1981
	Swindon	Remote Sens. Soc. Conf.	November, 1981
	Gorebridge	DAFS Land Branch Conf.	November, 1981
	London	Joint Meeting Photogram. Soc. and Remote Sens. Soc.	December, 1981
	Silsoe	NIAE Remote Sensing Course (3)	January
	Dundee	Inst. Phys.	February
	Aberdeen	Hydrograph. Soc.	September
	St Andrews	Brit. Cartog. Soc.	September
	Aberdeen	Remote Sens. Course for Land Cover Mapping (4)	September

	Place	Event	Date
Department of Spectrochemistry			
M. J. Adams	London	Remote Sens. Soc.	December, 1981
	Birmingham	RSC Ann. Chem. Congress	April
	Aberdeen	Robert Gordon's Inst. Tech. Seminar	May
M. L. Berrow	Pitlochry	RSC Annal. Division	March
	Sheffield	First Bienn. Nat. At. Spect. Symp.	July
	London	3rd Int. Envir. and Safety Conf.	September
J. C. Burridge	York	Trace Element Symp. BSAP/BVA	June
V. C. Farmer	London	Roy. Soc. Discuss. Mtg. Analyt. Chem.	December, 1981
A. M. Ure	Glasgow	RSC Anal. Div. Scot. Region	November, 1981
	Sheffield	First Bien. Nat. At. Spect. Symp.	July
Department of Soil Organic Chemistry			
H. A. Anderson	London	Amino Acid Anal. Users Gp.	March
M. V. Cheshire	London	Brit. Soc. Soil Sci. (Poster Display)	April
Department of Plant Physiology			
P. C. DeKock	York	Trace Elem. Discuss. Gp.	July
Department of Microbiology			
G. P. Sparling	Dundee	Soc. Gen. Microbiol.	September
G. Lethbridge	Dundee	Soc. Gen. Microbiol.	September
Department of Soil Fertility			
B. W. Bache	London	SCI Agric. Gp. Symp. " Phosphorus "	November, 1981
T. E. Edmonds	Stirling	Assoc. Scot. Industr. Analysts	August, 1982
Department of Statistics			
R. H. E. Inkson	Aberdeen	Univy. Postgrad Lectures (5)	January/March
Department of Soil Survey			
J. S. Bibby	Edinburgh	NATO Seminar	September
	Stirling	University Dept. of Envir. (2)	February/April
D. W. Futty	Thurso	DAFS/NOSCA Conf.	April
J. C. C. Romans	Aberdeen	University Dept. of Geog. Seminar	January
Director			
T. S. West	London	Roy. Soc. Discuss. Mtg. Analyt. Chem.	December, 1981
	Edinburgh	ARC Directors' Conf.	September

LIST OF PUBLICATIONS, 1981-82

The numbers appearing on the left-hand side of this list are the MISR serial numbers for the items. Please quote these numbers when asking for reprints, which are available free from the Librarian, Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen, AB9 2QJ. *Reprints with no serial numbers are only available if priced.* Items marked † are publications which can be bought from the Department of Soil Survey, at the above address.

ADAMS, M. J. Photoacoustic spectrometry. *Prog. Anal. Atom. Spectr.* 1982, **5**, 153-204.
A review is presented of recent advances in photoacoustic spectrometry. Current theoretical models and experimental systems are discussed. Three major areas of application have been identified, spectrochemical analysis, optical materials studies, and the use of the technique for the investigation of photoluminescence phenomena.

ADAMS, M. J. A microcomputer system for processing and analysis of remotely sensed data. *Proc. Remote Sensing Soc.: Matching Techniques and their Applications, London,* 1981, 427-430.
An analogue recorder-digital microcomputer system is described for the processing and analysis of remotely sensed data. Two application areas are discussed, the thermographic survey of Aberdeen City and the study of crop and soil reflectance spectra obtained with the aid of a portable spectrometer.

ADAMS, M. J. and BIRNIE, R. V. Aerial thermography of Aberdeen City: final report. *Macaulay Institute Report Commissioned by Aberdeen City Architects' Dept.*, 1982.

1217 ADAMS, M. J. and BLACK, I. Using a microcomputer in an infrared laboratory. *Anal. Proc.*, 1982, **19**, 470-472.
The use of an Apple II microcomputer is described as an aid in the acquisition and analysis of infrared spectral data. Data is obtained directly from a scanning spectrometer or *via* a digitising tablet, and can be fed to the spectrometer or a flatbed plotter. Computer manipulation of the digital data allows a detailed study of all recorded IR spectra.

ADAMS, M. J. and RITCHIE, P. Processing and analysis of thermographic data with the aid of a microcomputer. *Computer Applications,* 1981, **7**, 973-993.
On 11th December, 1980, an airborne thermal infrared survey of the City of Aberdeen was undertaken. Conventionally, a mainframe computer or a dedicated minicomputer is employed to store the large amounts of data obtained from such a study. It is demonstrated, however, that a microcomputer can be used to control the digitising, display and manipulation of such information. With the use of BASIC and machine-code routines the resulting system is fast, efficient and simple in operation.

1183 ANDERSON, H. A., BERROW, M. L., FARMER, V. C., HEPBURN, A., RUSSELL, J. D. and WALKER, A. D. A re-assessment of podzol formation processes. *J. Soil Sci.*, 1982, **33**, 125-136.
Chemical and physical processes which could lead to evolution of a profile along the genetic sequence Iron Podzol, Iron Humus Podzol, Peaty Podzol, are postulated. During the formation of an Iron Podzol, positively charged inorganic sols carry aluminium, silicon and iron from the A_2 horizon and deposit them in depth in the B_2 horizon; subsequently, with the development of an H layer, colloidal humus migrates through the A_2 horizon and precipitates on the positive colloids at the top of the B_2 horizon to form a B_h horizon, whose colour is possibly enhanced by remobilized ferric species trapped by the organic matter. In higher rainfall areas, occasional water-logging above the oxide-impregnated B_2 horizon will lead to a thin iron pan, separating permanently oxidizing conditions below from seasonal water-logged and reducing conditions above.

BACHE, B. W. Phosphorus uptake by ryegrass in relation to quantity/intensity buffer curves of some contrasting soils. *J. Sci. Fd. Agric.*, 1982, **33**, 733.

BACHE, B. W. The role of soil in determining surface water composition. *Proc. Int. Conf. Coal Fired Power Plants and the Aquatic Environment, Copenhagen*, 1982, 434-446.
Surface waters (streams and lakes) derive their water from precipitation of rain and snow from the atmosphere. The composition of solutes in these waters is a reflection of both the composition of the precipitation, and the changes that have taken place in it when it flows over or through land surfaces. This review cites a number of examples to show that the main factor determining surface water composition is the composition of the soil or rock through which it flows, but that this can be modified by the hydrologic pathway of the water through a catchment.

1170 BACHE, B. W., FROST, C. A. and INKSON, R. H. E. Moisture release characteristics and porosity of twelve Scottish soil series, and their variability. *J. Soil. Sci.*, 1981, **32**, 505-520.
Soil information on which to base advice on physical management problems is lacking in Scotland. To help obtain this information and to assess its variability within soil series, particle size distribution, bulk density and moisture release characteristics were measured at nine sites for each of twelve series. Available water capacity and pore space relationships were calculated. Mean values of the parameters gave a reasonable guide to the behaviour of the series for only a few series which showed low variability, while many of the series showed high variability. The most useful parameter, apart from texture, was the drainable pore space of B horizons, which showed the largest and most significant differences between series, and is related to the drainage properties of the soil profile.

BELL, M. V., PIRIE, B. J. S., McPHAIL, D. B., GOODMAN, B. A., FALK-PETERSEN, I. B. and SARGENT, J. R. Contents of vanadium and sulphur in the blood cells of *Ascidia Mentula* and *Ascidiella Aspersa*. *J. Marine Biol. Assoc. U.K.*, 1982, **62**, 709-716.
In work carried out mainly at the Institute of Marine Biochemistry, Aberdeen, it has been shown that vanadocytes in the blood cells of the ascidians *Ascidia mentula* and *Ascidiella aspersa* contain large amounts of vanadium and sulphur. Numerous other cell types were shown to be rich only in sulphur, which was present in all cases as sulphate. Electron paramagnetic resonance spectroscopy was used to show that a small amount of the vanadium in the vanadocytes was present as the oxo-vanadium (IV) ion, partly as the solvated ion and partly as an organic complex.

BERROW, M. L. Citation Classic. *Current Contents*, 1982, **13** (30), 18.
A brief commentary and abstract of work carried out on trace element levels in sewage sludges has been prepared for publication in the Citation Classics section of Current Contents.

BERROW, M. L. and BURRIDGE, J. C. Persistence of metals in available form in sewage sludge treated soils under field conditions. *European Society for Nuclear Methods in Agriculture Environmental Pollution Newsletter*, 1981, 46-52.

1158 BERROW, M. L. and REAVES, G. A. Trace elements in Scottish soils developed on Greywackes and shales. Variability in the total contents of basal horizon samples. *Geoderma*, 1981, **26**, 157-164.
The variability in total contents of eight trace elements (Co, Cu, Ga, Mn, Ni, Pb, Ti and V) in basal horizon samples of soil profiles of the Ettrick Association has been examined. The ranges of total contents of all the elements are quite wide but nevertheless fall well within the limits commonly found for soils. The distributions of all elements are positively skewed: a logarithmic transformation reduced skewness and kurtosis to insignificant levels suggesting that the contents of each element may be log-normally distributed. Although the mean contents of cobalt and copper are above those at which plant or animal deficiencies of these

elements might generally be anticipated, the levels in some samples, especially from the north-east of the area, are low enough to suggest that some localised deficiencies are likely to occur.

1168 BERROW, M. L. and URE, A. M. The determination of metals and metalloids in soils. *Environmental Technology Letters,* 1981, **2**, 485-502.
The analysis of soils in powder form using emission spectrometry, X-ray fluorescence spectrometry, spark source mass spectrometry and neutron activation analysis is briefly discussed. The problems involved in the dissolution of soils for analysis in solution form are considered and some results obtained using atomic absorption spectrophotometry following different dissolution procedures presented. Recent developments in the use of inductively coupled plasma sources for the analysis of soils and soil extracts are briefly reviewed.

1207 BERROW, M. L., DAVIDSON, M. S. and BURRIDGE, J. C. Trace elements extractable by 2-ketogluconic acid from soils and their relationship to plant contents. *Plant and Soil,* 1982, **66**, 161-171.
The use of 2-ketogluconic acid (2-KG), a naturally occurring acid produced by soil bacteria in the rhizosphere, as a soil extractant for trace elements was investigated. More Co, Ni and Zn and considerably more Fe, Ti and V was generally extracted by 2-KG than by ammonium acetate at the same pH, indicating that 2-KG chelates a portion of the non-exchangeable forms of these elements in the soil. The amounts of Cu, Mn, Mo, Ni and Zn extractable by 2-KG from three different soils are reflected in the contents of these elements in pasture herbage species growing on them. This chelate shows promise as a diagnostic extractant for a number of trace elements in soils and may promote the availability of such biologically important elements as Co, Cu and Zn to plants under natural conditions.

BIBBY, J. S. Soil survey and its interpretation for agriculture in the West Highlands: In: *Soils and Upland Management: Welsh Soils Discussion Group Report No. 20,* 1979, 33-47.
The methods of soil survey currently in use in an area of mountainous terrain in Western Scotland are described and an explanation given of how the results of soil survey are being interpreted for use in land planning.

1205 BICK, W., VERGNANO GAMBI, O. and DeKOCK, P. C. A relationship between free amino acid and nickel contents in leaves and seeds of *alyssum bertolonii. Plant and Soil,* 1982, **66**, 117-119.
An analysis has been carried out on the free amino acid and nickel contents of leaves of *alyssum bertolonii,* which grows on serpentine outcrops in Tuscany, Northern Italy. The amino acids are at their maximum concentrations in February, but their concentrations decrease during the growing season, reaching a minimum in June before again increasing by October. The changes in the total free amino acids in the leaves are paralleled by changes in the nickel content of the tissues.

BIRNIE, R. V. Aberdeen thermal infrared survey: some implications for agricultural research. *Proc. Conf. Matching Remote Sensing Technologies and their Applications, London,* 1981, 163-166.
High resolution night-time thermal infrared (10-14 μ) imagery of the agricultural area around Aberdeen is examined. The appearance and distribution of wind-induced thermal shadowing is used to define shelter effects. Variations in tree-canopy radiant temperatures are apparently related to near-surface air temperature stratification and are used to identify frost hollows. Differences in radiant temperatures of field crops are linked to management practices.

BIRNIE, R. V. and GAULD, J. M. A major European Experiment on the Application of Synthetic Aperture Radar (SAR) for natural resource surveys and agricultural monitoring applications in Scotland. *Soil Survey and Land Evaluation,* 1982, **2**, 20.
The background to an experiment designed to evaluate the application of Synthetic Aperture Radar as an all-weather capability for resource surveys and agricultural monitoring applications in Scotland is discussed.

1204 BIRNIE, R. V., ROBERTSON, R. A. and STOVE, G. C. Remote sensing for agricultural research and monitoring operations. *Agriculture and Environment*, 1982, **7**, 121-134.
Agricultural Remote Sensing at the Macaulay Institute for Soil Research is examined in three parts. The first and second outline the historical development of the remote sensing facility and its present applications. The third part deals with future developments in remote sensing techniques and information sources, and their implications for agricultural problems.

BIRNIE, R. V., ROBERTSON, R. A. and STOVE, G. C. Remote Sensing in peat resource survey. *Proc. Symp. Peat, Thunder Bay, Canada*, 1981, 95-109.
The importance of peatlands for forestry and agriculture and as a source of raw materials for horticulture, fuel and other industrial applications is being increasingly recognized at both national and international level. In Scotland, current committments to undertake a series of peat, vegetation and land-use surveys have necessitated the development and application of remote sensing and photogrammetric techniques for resource mapping and evaluation. This paper emphasises the importance of a systematic approach based on the acquisition and analysis of multi-band aerial photography and space imagery and the development of a peat data bank, photogrammetric system and computer programmes for the processing of digital information. The methodology has been particularly useful in mapping and classifying large areas and has wider application for monitoring change in land-use and other terrain features.

†BIRSE, E. L. Plant Communities of Scotland: a preliminary phytocoenonia. *Soil Survey of Scotland Bull. No. 4.* Aberdeen, Macaulay Institute, 1980. £15.

1218 BIRSE, E. L. Plant communities on Serpentine in Scotland. *Vegetatio*, 1982, **49**, 141-162.
The plant communities on serpentine are named, classified and briefly described. Vegetation specific for serpentine belongs to Violetea calaminariae, the class of communities on heavy metal soils. Other individual associations occur on serpentine soils, but these are part of more general classes. The relationship of the separate vegetation units with the soils and also their range in climate are outlined.

1186 BIRSE, E. L. The main types of woodland in North Scotland. *Phytocoenologia* 1982, **10**, 9-55.
The main woodland communities of North Scotland, north of latitude 56° 30′ N., have been recorded, named and classified. They include the native pinewood, three types of oakwood and birchwood, western ash-oak wood, elmwood, flush alderwood, swamp alderwood and an unclassified scrubby birchwood on acid peaty soils. The relationship of individual communities and their sub-units with relief, climate and soils has been elaborated, together with their general distribution in North Scotland.

BLACK, J. G. (Memorial, Univ., St John's, Canada). Software development for regression and trend surface analysis. Aberdeen, Macaulay Institute for Soil Research, Internal Report, 1982.

BONNEAU, M. and SOUCHIER, B. *ed.* Constituents and properties of soils. Translation ed. by V. C. Farmer. London, Academic Press, 1982.

1173 BRACEWELL, J. M. and ROBERTSON, G. W. The analytical potential of pyrolysis products from soil organic matter. *Anal. Proc.*, 1981, **18**, 532-535.
The experimental conditions required in analytical pyrolysis are reviewed and the pyrolytic decomposition products of lignins, polysaccharides, polypeptides, and soil humic polymers, amongst others, are described. Changes in the relative abundances of these products enable the humification process to be followed and various humus types to be distinguished. The pyrolysis products can be related to organic structure with the aid of model compounds and polymers.

BROWN, K. W. M. Analysis of NCB Keirsbeath data. Aberdeen, Macaulay Institute for Soil Research, Internal Report, 1982.

1194 BUCHAN, G. D. Predicting bare soil temperature. I. Theory and models for the multi-day mean diurnal variation. *J. Soil Sci.* 1982, **33**, 185-197.
The temperature of bare soil (e.g. in the seedbed) is controlled by its thermal properties and the variation with time of the surface temperature. The latter is in turn a function of meteorological variables—solar radiation, air temperature and humidity, windspeed and cloud cover—plus the surface and bulk properties of the soil. Two theoretical models are described which predict the diurnal variation of soil temperature from given soil and meterological data. By averaging the time-variation over periods between one and thirty days, their results describe the "climate" rather than the "weather" of the soil. The models are designed for application during spring and autumn in humid temperate regions.

1195 BUCHAN, G. D. Predicting bare soil temperatures. II. Experimental testing of multi-day models. *J. Soil Sci.* 1982, **33**, 199-209.
Two theoretical models to predict the diurnal variation of bare soil temperature from meteorological and soil data, have been tested experimentally using measurements from a field site near Aberdeen. In spring and autumn, soil temperature can be computed within 0.3°C of measurement to a depth of 32 cm. In the summer, only surface temperature is accurately predicted, the bulk temperature lagging due to its earlier spring history. The simplest practicable model requires 4 or 6 measurements per day of solar radiation and air temperature, and only average values of the other input variables.

1211 BUCHAN, G. D. Predicting bare soil temperature. III. Extension to single-day variation. *J. Soil Sci.* 1982, **33**, 365-373.
Earlier theory to predict the daily variation of bare soil temperature, under typical seedbed conditions, from climatic and soil data is extended to give a new model for the soil thermal "weather" experienced on a given day. The model allows mathematically for an overall climb or descent (between 0 and 24 hours) in the temperature wave, and for the preceding history of the soil, integrated into its starting (midnight) temperature profile. Experimental tests against spring and autumn data from a field site near Aberdeen show that the model can successfully predict the daily wave of temperature at depths down to 60 cm.

CHESHIRE, M. V. Structure and function of soil polysaccharides. *Proc. XIth Int. Carbohydrate Symp., Vancouver,* 1982.
The structure of soil polysaccharide has been investigated by methylation of the whole soil. After seven consecutive treatments, chloroform-soluble methylated product was isolated equivalent to about one-third of the organic matter. Sugars liberated on hydrolysis were equivalent to about 40% of the carbohydrate content of the soil. There was a large proportion of (1→3) linked hexose units. Considerable carbohydrate remains after sodium periodate and tetraborate treatment of the soil. This may be the result of branching and large numbers of (1→3) linkages in the polysaccharide structure, either of which enable sugars to resist oxidation by periodate.

1169 CHESHIRE, M. V. and MUNDIE, C. M. The distribution of labelled sugars in soil particle size fractions as a means of distinguishing plant and microbial carbohydrate residues. *J. Soil Sci.* 1981, **32**, 605-618.
Soil carbohydrate components in plant residues or microorganisms have been selectively labelled with ^{14}C and their separation by particle size fractionation studied. Carbohydrate of microbial origin derived from glucose was found mainly in the clay and silt fractions whereas that of plant origin was concentrated in the sand fractions. The changes in the distribution with time of incubation allow a consideration of the nature of the native soil polysaccharide to be made.

1206 CHESHIRE, M. V., BICK, W., DeKOCK, P. C. and INKSON, R. H. E. Effect of copper and nitrogen on the amino acid composition of oat straw. *Plant and Soil* 1982, **66**, 139-147.

Copper-deficient oat leaves contain more free amino acids than do normal leaves and this is accentuated by added nitrogen, either in the form of nitrate or ammonium, but the latter gives greater free amino acid values. The accumulation of aspartic acid is particularly pronounced in the copper-deficient tissue. It is suggested that this is related to the change in redox potential of the cell, which is largely controlled by copper.

1174 DeKOCK, P. C., HALL, A. and INKSON, R. H. E. Cavity spot of carrots. *An. Edafol. Agrobiol,* 1981, **40**, 307-316.
The causes of cavity spot in carrots have been investigated and the similarities drawn between this disorder and blossom-end rot of tomatoes and sub-apical necrosis of potato sprouts. The potassium-calcium ratio is of importance in the appearance of the disorder, high values leading to calcium deficiency and concurrent cell wall necroses are induced by absorption of nitrogen in the ammonium form. Waterlogging of soils causes loss of nitrate from soils by denitrification but the ammonium ion is left in the soil and causes cavity spot to appear.

1192 DeKOCK, P. C., INKSON, R. H. E. and HALL, A. Blossom-end rot of tomato as influenced by truss size. *J. Plant Nutr.,* 1982, **5**, 57-62.
Thinning of fruit to one or two fruits per truss increases the size of the fruits but subsequent trusses become severely affected by blossom-end rot. This is thought to be due to an excessive supply of growth promoting hormones from the roots to the developing fruits.

1196 DeKOCK, P. C., HALL, A., BOGGIE, R. and INKSON, R. H. E. The effect of water stress and form of nitrogen on the incidence of blossom-end rot in tomatoes. *J. Sci. Fd. Agric.,* 1982, **33**, 509-515.
A study was made of water stress on the incidence of blossom-end rot (BER) in tomatoes, which were supplied with nitrogen as sodium nitrate, ammonium sulphate or ammonium nitrate. It was shown that BER incidence was related to the presence of the ammonium ion and that moisture stress had little effect in this study. Ammonium and nitrate ions accumulated in both the peat and in the leaves under water stress and the high levels of ammonium ions found may explain the relation between BER and moisture stress reported by others. Accumulation of potassium and magnesium salts also occurred in the peat substrates of the dry treatments. Both these elements have been shown to contribute to BER incidence.

1200 EDMONDS, T. E. The differential pulse polarographic determination of extractable molybdenum in soil. *Comm. Soil Sci. Plant Anal.,* 1982, **13**, 1-6.
A method is described for the differential pulse polarographic determination of molybdenum extracted from soil by neutral molar ammonium acetate. The useful determination range is 0.02 to 0.2 mg kg^{-1} molybdenum in air-dry soil.

1223 EDMONDS, T. E. and COUTTS, G. Residual currents at the static mercury drop electrode. *Anal. Chem.,* 1982, **54**, 2105-2107.
A method is described for overcoming the problem of large residual currents in polarographic analysis. The technique is only applicable to the static mercury drop electrode. At the " traditional " dropping mercury electrode, solutions in which these large residual currents arose would require some form of pretreatment.

EGAN, H. and WEST, T. S. *ed.* Collaborative interlaboratory studies in chemical analysis. *Proc. IUPAC Symp., Helsinki,* 1981. Oxford, Pergamon Press, 1982, 171.

1198 FARMER, V. C. Recent advances in analytical infrared spectroscopy. *Phil. Trans. R. Soc. London,* 1982, A**305**, 609-619.
A review of recent developments in infrared instrumentation and applications is presented. Wider use of the technique to characterize minerals and biological materials is critically dependent on the availability of detailed monographs on specific groups of compounds, to give potential users readier access to sound correlations of spectra and structure.

1190 GAULD, J. H. Native pinewood soils in the northern section of Abernethy Forest. *Scot. Geogr. Mag.*, 1982, **98**, 48-56.
The morphological and environmental characteristics of the dominant soils, iron and humus iron podzols, found within the northern section of Abernethy Forest, are discussed along with their possible variation in profile morphology and their analytical properties. Beneath a native pinewood, the humus iron podzol subgroup is widespread, but other podzol subgroups, and peat and peaty gley, are also to be found. Considerable significance is attached to the studies in relation to future ecological studies and to the management and conservation of native pinewood habitats, both in Speyside and throughout Scotland.

1222 GOODMAN, B. A. and CHESHIRE, M. V. Reduction of molybdate by soil organic matter: EPR evidence for the formation of both Mo(V) and Mo(III). *Nature*, 1982, **299**, 618-620.
The reducing ability of organic fractions extracted from the soil is well known and in the present work the reduction of molybdate, Mo(VI), by humic acid and polysaccharide components from peat and soil, respectively, has been studied by electron paramagnetic resonance (EPR) spectroscopy. Reduction to Mo(V) species occurred initially, but with the humic acid, evidence was obtained for reduction of part of the molybdenum to Mo(III).

1202 GOODMAN, B. A. and DeKOCK, P. C. Mössbauer studies of plant materials. I. Duckweed, stocks, soyabean, pea. *J. Plant Nutr.*, 1982, **5**, 345-353.
Specimens of duckweed, stock (single- and double-flowered), soyabean and pea were grown in nutrient solutions containing iron primarily as the ^{57}Fe isotope. Whole duckweed and the separated roots, stems and leaves from the other plants were studied by Mössbauer spectroscopy at 77K. Samples of duckweed and pea were also dried in air and studied at room temperature. All specimens showed the presence of iron in the ferric form and in addition the pea leaves indicated the presence of some ferrous iron.

1201 GOODMAN, B. A., DeKOCK, P. C. and RUSH, F. D. (Univ. Liverpool). Mössbauer studies of plant materials. II. Spectra of ^{57}Fe-enriched duckweed at low temperatures. *J. Plant Nutr.*, 1982, **5**, 355-362.
Samples of ^{57}Fe-enriched duckweed have been studied by Mössbauer spectroscopy at 4.2 and 1.3K and at 4.2K in the presence of both small and large magnetic fields. The results suggest that, as in previous studies, the iron is in the ferric form, probably as a form of ferritin with particle size of 15Å.

1220 GORDON, D. C., MacDONALD, I. R. and HART, J. W. (Univ. Aberdeen). Regional growth patterns in the hypocotyls of etiolated and green cress seedlings in light and darkness. *Plant, Cell and Environment*, 1982, **5**, 347-353.
A description is given of a specially-designed growth chamber which offers unique advantages in time-lapse photography of seedling growth as influenced by light and gravity. Green and etiolated cress seedlings are shown to differ in their immediate response to irradiation.

1221 HART, J. W. (Univ. Aberdeen), GORDON, D. C. and MacDONALD, I. R. Analysis of growth during phototropic curvature of cress hypocotyls. *Plant, Cell and Environment*, 1982, **5**, 361-366.
The growth rates on either side of a cress hypocotyl bending towards the light were monitored with time-lapse photography. It is shown that curvature is a consequence of an integrated sequence of changes in growth rate involving both deceleration and promotion of growth on each side of the hypocotyl. The bearing of these findings on the Cholodny-Went theory of photocurvature is discussed.

1172 HAWKSWORTH, D. L. and JONES, D. *Sclerococcum Sphaerale* obtained in pure culture. *Trans. Brit. Mycol. Soc.*, 1982, **77**, 485-489.
During studies on the microbiological weathering of minerals, a fungus parasitizing a rock-encrusting lichen has been obtained in culture on artificial media for the first time. Physiological studies, hitherto not feasible, can now be made on this fungus.

†HESLOP, R. E. F. and CAMPBELL, C. G. B. Soil survey map of Tomintoul (Sheet 75). Scale: 1:63 360. Southampton, Ordnance Survey, 1981. £1.20. Folded £1.50.

1179 JONES, D. and ONIONS, A. H. S. Scanning electron microscopy of critical point dried *Acremoniella Velata*. *Trans. Brit. Mycol. Soc.*, 1982, **78**, 182-183

Scanning electron microscopy has enabled remarkable advancements to be made in our knowledge of surfaces of biological specimens. Great care, however, is needed to preserve the integrity of the morphological features recorded since the instrument operates under high vacuum. This note reports on ultrastructural features of the spores of a soil fungus, hitherto not adequately recorded because of limitations imposed either by light microscopy or by the lack of a suitable preservation technique in scanning electron microscopy.

1160 JONES, D., WILSON, M. J. and McHARDY, W. J. Lichen weathering of rock-forming minerals; application of scanning electron microscopy and micro-probe analysis. *J. Microsc.*, 1981, **124**, 95-104.

Since the ultimate sources of the inorganic nutrients required to sustain and nourish higher plants in nature are the minerals in the earth's crust, the weathering of these materials to release available elements is of fundamental importance to agricultural scientists. Using scanning electron microscopy and electron probe microanalysis the weathering of a variety of rock-forming minerals by various species of encrusting lichens has been studied. The evidence obtained indicates that marked etching of the minerals results, in the main, through the activity of oxalic acid secreted by the lichens. Secondary decomposition products are deposited as insoluble salts of oxalates some of which contain heavy metals including manganese, zinc and nickel.

1178 KHALIGIE, J., URE, A. M. and WEST, T. S. Atom trapping atomic absorption spectrometry with water-cooled metal collector tubes. *Anal. Chim. Acta.*, 1982, **134**, 271-281.

Water-cooled metal collector tubes have some advantages for the determination of volatile trace elements such as cadmium and selenium by atom-trapping atomic absorption spectrometry, but suffer disadvantages relative to silica collector tubes for other trace elements.

1214 LAU, C. M., URE, A. M. and WEST, T. S. The determination of selenium by atom trapping atomic absorption spectrometry. *Anal. Chim. Acta*, 1982, **141**, 213-224.

The sensitive new technique of atom trapping atomic absorption spectroscopy developed in the Institute has been successfully applied to the determination of traces of selenium in plant tissue samples.

1177 LETHBRIDGE, G., DAVIDSON, M. S. and SPARLING, G. P. Critical evaluation of the acetylene reduction test for estimating the activity of nitrogen-fixing bacteria associated with the roots of wheat and barley. *Soil. Biol. Biochem.*, 1982, **14**, 27-35.

The acetylene reduction test is a rapid and sensitive indicator of nitrogen-fixing activity. However, it is unsatisfactory for estimating the activity of nitrogen-fixing bacteria associated with the roots of wheat and barley grown in soil. The problem is one of over-estimation, with the concomitant possibility of deducing the existence of nitrogen fixation where there is none. Experiments with 9 cereal cultivars, grown in a glasshouse in 9 soils, suggested that even if all the acetylene reduction observed represented real nitrogen fixation, these nitrogen-fixing bacteria do not contribute significantly to the nitrogen required by wheat and barley grown under field conditions in Scotland.

1219 MacDONALD, I. R. HART, J. W. (Univ. Aberdeen) and GORDON, D. C. Analysis of growth during light-induced hook opening in cress. *Plant, Cell and Environment*, 1982, **5**, 355-360.

The emergence of the seedling through the soil surface is a vital stage in seedling establishment, survival being dependent on the efficient raising of the cotyledons into the light. This study investigates the hypocotyl growth kinetics which achieve this end. It is shown that growth of the

seedling in the dark is by extension of the shank especially the upper zones. When the seedling is exposed to light, the previously growing regions of the shank become inhibited, while the non-growing zones in the inner side of the hook begin to grow rapidly, thus leading to the opening of the hook.

1189 McHARDY, W. J., WILSON, M. J. and TAIT, J. M. Electron microscopy and X-ray diffraction studies on filamentous illitic clay from sandstones of the Magnus Field. *Clay Minerals*, 1982, **17**, 23-39.
It is often difficult to assess the effect of drying techniques on the results obtained under the electron microscope for soils or other sensitive materials. Three methods (air drying, freeze drying and critical point drying) were therefore tested on a sandstone whose permeability is known to alter markedly on air drying. This sandstone contains filamentous material in its pores and the appearance under the scanning electron microscope is very dependent on the drying technique used. Only critical point drying showed the arrangement of the filaments in the pores. The filamentous mineral occurs in ribbons 40-70 nm wide by up to above 25 μm in length and 2-3 silicate layers thick, but gives an X-ray diffraction pattern indicating an interstratified illite-smectite with about 20% smectite. Reasons are discussed.

MACKENZIE, R. C. Down-to-earth thermal analysis. *Thermal Analysis: Proc. 7th Int. Conf. Thermal Anal., Kingston, Ontario.* Vol. 1. Edited by B. Miller. London, Wiley, 1982, 25-36.
Although many early developments in thermal analysis were associated with the earth sciences or, more correctly, with earth-derived materials, there seems at present to be a geographical variation in the extent of the application of thermoanalytical techniques in such fields: possible reasons are examined. The potential of thermoanalytical techniques is assessed from the viewpoint of their application to the soil, a complex system that can range from almost 100% mineral to almost 100% organic matter and can therefore be taken as covering the complete mineral-to-biological and inorganic-to-organic fields.

MACKENZIE, R. C. The story of the platinum-wound electric resistance furnace. *Platinum Metals Rev.*, 1982, **26**, 175-183.
Although the wire-wound electrical resistance muffle or furnace is a standard piece of laboratory equipment widely used for the heat-treatment of mineral and organic materials, its early history is not to be found in any standard reference work. The first wire-resistance furnace was conceived by W. H. Pepys in 1815, but his work was not followed up and the platinum-wound furnace in its present form originated with Georges Charpy in Paris in 1893-95. Charpy even constructed a rotating, pivoted model with water-cooled ends. Such furnaces and muffles were commercially produced about the turn of the century by W. C. Heraeus, Germany, and most technological development had taken place by 1912.

MACKENZIE, R. C. Thermal analysis and some analytical applications. *Anal. Proc.*, 1982, **19**, 202-204.
A brief review is given of some analytical applications of the techniques of thermogravimetry, derivative thermogravimetry, differential thermal analysis, differential scanning calorimetry and evolved-gas analysis.

1191 MACKENZIE, R. C., PATERSON, E. and SWAFFIELD, R. Observation of surface characteristics by DSC and DTA. *J. Thermal Anal.*, 1981, **22**, 269-274
Differential thermal analysis as well as differential scanning calorimetry can give useful information on the surface constitution of particles of the oxyhydroxide of iron, goethite (a common mineral in soils), provided suitable experimental conditions are chosen. With synthetic samples it has been found that the main requirement is that the water produced by condensation of surface hydroxyl groups must be rapidly removed as it is formed: it is also necessary that the particles be small so as to give a high surface-to-volume ratio.

1176 McLEOD, C. W. M. and WEST, T. S. Spectroelectrochemistry of morphine and related alkaloids and their investigation by fluorescence in a gold micromesh cell. *Analyst.*, 1982, **107**, 1-11.
A standard microflow cell containing a transparent gold micromesh electrode has been designed *in situ* fluorescence monitoring of electrogenerated species by frontal illumination. Oxidative dimerisation of morphine to the fluorescent pseudomorphine proved to be a model fluorogenic reaction for study. The fluorescence calibration graph was linear over the concentration range of 0.001M to 0.000001M and the limit of detection was 0.0000005M. The procedure, which is selective and free from interference from most of the opium alkaloids enabled morphine to be directly assayed in the pharmaceutical, papaveretum.

McPHAIL, D. B., LINEHAN, D. J. and GOODMAN, B. A. An electron paramagnetic resonance (EPR) study of the uptake of vanadyl by wheat plants. *New Phytol.*, 1982, **91**, 615-620.
EPR spectroscopy has been used to monitor, *in vivo*, the uptake of the vanadyl ion by wheat plants. The use of high levels of vanadyl ion produced, in the plant, high molecular weight complexes with EPR parameters similar to those obtained from cellulose-vanadyl derivatives. With lower vanadyl concentrations, low molecular weight complexes were observed and interpreted as arising from vanadyl-organic acid and vanadyl-amino acid complexes. Low molecular weight complexes with similar parameters were obtained from root washings.

1157 MILLER, H. G. Aspects of forest fertilization practice and research in New Zealand. *Scott. For.*, 1981, **35**, 277-288.
This report, prepared following a visit to North Island, New Zealand, discusses (a) fertilization of *Pinus radiata* in the nursery, at establishment and subsequent to canopy closure, (b) sand dune afforestation techniques developed in New Zealand, in particular nitrogen fertilization and the use of *Lupinus arboreus* to enrich the soil through fixation of atmospheric nitrogen, and (c) current nutrition research in New Zealand, including nutrient cycling, soil leaching studies and the practicality of producing alcohol fuels from forest biomass.

1161 MILLER, H. G. Forest fertilization: some guiding concepts. *Forestry*, 1981, **54**, 157-167.
Drawing on results from studies by the author and his colleagues on nutrient cycling and fertilizer response in pine, three concepts are proposed: (1) generally fertilizers are applied to the trees, not the site, and very long-term responses are only likely if the amount applied is large in relation to the nutrient capital of the site; (2) in the absence of any long-term effect, fertilizer response is best explained by using the simple analogy of an acceleration through time; (3) consideration of the variations with tree age in the patterns of nutrient uptake, cycling and immobilization, and in the capture and retention of atmospheric nutrients, identifies three distinct nutritional stages. During the years prior to canopy closure (Stage I) response to a range of fertilizer nutrients can be anticipated. Thereafter, (Stage II) responses are unlikely unless the foliage biomass has to be reconstructed, e.g. after thinning. However, as trees age on low nitrogen capital sites, immobilization in biomass and humus may lead to the progressive development of nitrogen deficiency (Stage III)..

1197 MILLER, H. G. Nutrient cycling in relation to tree growth and soil development. In: *Soils and Upland Management: Welsh Soils Discussion Group Report No. 20*, 1979, 169-192.
The cycles that (a) introduce nutrients to and remove them from the forest site, (b) transfer nutrients between zones of accumulation within the ecosystem, and (c) move nutrients within the tree, are discussed and are illustrated by recent research findings. In attempting to identify and understand those pathways of nutrient transfer that may have a critical influence on tree growth, it is necessary to consider three stages in the life of the tree crop: (i) establishment, with the soil the main supplier of nutrients, (ii) post canopy-closure, with nutrient input from the atmosphere now an important factor, and (iii) late-rotation, when nitrogen deficiency may result from excessive immobilization in the humus layer.

MILLER, H. G. Priorities in forestry research: soils. *ULC/NERC Workshop on Forestry Research Priorities, University College, London,* 1982.
Future forest-related soil research with need to respond both to public concern about the environmental consequences of afforestation and to the need to maintain or improve levels of production from upland forests despite lower levels energy inputs than have hitherto been considered necessary. Important research areas include nutrient cycling and its change with tree age, the development of root systems and associated myccorhizal fungi, organic matter decomposition and nitrogen dynamics, soil compaction (particularly in relation to harvesting techniques), drainage and cultivation and their interaction with stability and the input, retention and loss to streams of pollutants.

1162 MILLER, H. G., MILLER, J. D. and COOPER, J. M. Optimum foliar nitrogen concentration in pine and its change with stand age. *Canad. J. For. Res.,* 1981, **11**, 563-572.
Discrepancies in the reports available on the levels of nitrogen in foliage that are associated with optimum growth of pine prompted the establishment of two hydroponic experiments in the glasshouse, and two forest fertilizer experiments, designed to cover the full response range of *Pinus nigra* var *maritima* (Ait.) Melv. These showed that during the years prior to canopy closure optimum nitrogen concentrations decline with the logarithm of tree weight, but thereafter rise again and, furthermore, that the optimum for height is usually lower than that for other growth parameters. Although inclusion of climatic factors improved the relationships for the forest experiments the optima remain unaltered. It is concluded that for diagnostic purposes critical foliar levels must be qualified by age or developmental stage of the trees.

MILLER, H. G., ANDERSON, F., NILSSON, S. I. (Swedish Univ. Agric. Sci., Uppsala, Sweden) and EFFER, W. R. (Ontario Hydro, Toronto, Canada). Impacts of acid deposition on vegetation, soil, drainage water and streams. In: *Effects of SO_2 and its Derivations on Health and Ecology. Vol. 2. Natural Ecosystems, Agriculture, Forestry and Fisheries. Chapter 4.* (Leatherhead). International Electric Research Exchange, 1981.
On behalf of the International Electrical Research Establishment a wide ranging survey was undertaken of the literature on the effects of acid rain (resulting from anthropogenic sulphur dioxide) on natural vegetation, managed forests, soils and stream water. From 149 papers finally chosen for critical assessment it was concluded that there is little danger of direct damage to vegetation or of pronounced soil changes, except in specific and limited soil types. However, the combination of acid rainfall, resistant geology and rapid flow into streams may well result in streams receiving water bearing unsually high concentrations of both hydrogen and aluminium ions.

1193 MUIR, J. W. and LOGAN, J. Eluvial/illuvial coefficients of major elements and the corresponding losses and gains in three soil profiles. *J. Soil. Sci.,* 1982, **33**, 295-308.
The losses and gains of major-elements from and to the horizons of three soil profiles are determined and related to the morphologies of the profiles. The profiles belong to the Bruntland, the Charr and the Gaerlie series. The principal soil-forming process operating in these soils is the breakdown of easily weathered minerals and the subsequent loss to drainage of significant amounts of magnesium, sodium, potassium, calcium, aluminium and iron. One of the profiles, that belonging to the Bruntland series, has lost a large amount of silica.

1209 NILSSON, S. I. (Swedish Univ. Agric. Sci., Uppsala, Sweden), MILLER, H. G. and MILLER, J. D. Forest growth as a possible cause of soil and water acidification: an examination of the concepts. *Oikos.,* 1982, **39**, 40-49.
Acidity consequent on root uptake was calculated as the rate of excess cation accumulation in the trees for a range of forest types, and values were also derived for acidity resulting from the accumulated humus. In addition, a model was constructed of the rate of accumulation of excess cations throughout the forest rotation. From comparison with measured

rates of hydrogen ion input in rainwater it is suggested that because of differences in pattern, location and method of introduction between the two sources, rainwater acidity is the more likely to lead to stream-water acidification whereas root uptake will primarily acidify the soil.

1225 NOMURA T. and YAMASHITA, T. (Dept. Chemistry, Shinshur Univ., Matsumoto, Japan) and WEST, T. S.
Determination of lead in aqueous solution by adsorption of the extracted oxinate on the electrodes of a piezoelectric quartz crystal detector. *Anal. Chim. Acta.*, 1982, **143**, 243-247.
The piezoelectric effect is used to determine lead in micromolar concentrations in aqueous solution. Lead is extracted into chloroform as its 8-Quinolinolate and a 9 MHz A/T-cut quartz crystal is immersed in the extract. Adsorption of the lead chelate on the crystal causes a change in the frequency of oscillation of the crystal which can be measured and, through the Sauerbrey equation, related to the concentration of lead. The interference of co-extractable ions, *viz.* Ag, Cd, Co(II), Fe(III), Ni and Zn can be eliminated by addition of L-ascorbic acid and cyanide before the extraction stage.

PATERSON, E. and STAWINSKI, J. J. (Inst. Agrophysics, Lublin, Poland.)
The use of a vacuum microbalance in the investigation of the kinetics of water vapour sorption on soil components. *Polish J. Soil Sci.*, 1979, **12**, 105-111.
The use of a vacuum electrobalance in the study of the kinetics of water-vapour adsorption and desorption on kaolinite, illite, montmorillonite and the $<5\mu$m fraction of a soil from Tipperty, Aberdeenshire, has been assessed. The method devised should prove to be of considerable value in measuring the kinetics of this process.

1188 PATERSON, E., SWAFFIELD, R. and CLARK, D. R. Thermal decomposition of synthetic akaganeite (β-FeOOH). *Thermochim. Acta.*, 1982, **54**, 201-211.
As part of a study of the characteristics of iron oxides and oxide hydroxides in soils the thermal decomposition of β-FeOOH has been studied using differential thermal analysis and thermogravimetry in conjunction with X-ray diffraction and electron microscopy. The results show that, in common with goethite (α-FeOOH), a reaction involving surface hydroxyl groups precedes the main dehydoxylation reaction, but that, unlike α-FeOOH the structure of the dehyroxylate is dependent on the atmosphere in which the sample is heated. This is thought to be due to the chloride content of the synthetic product.

ROBERTSON, R. A. Peat resource survey and utilization in Scotland. *Int. Peat Symp., Bemidji, Minn., U.S.A.*, 1981, 539-555.
In Scotland, deep peat covers some 800,000 ha or approximately 10 per cent of the land area. The nature and distribution of this not inconsiderable resource are outlined and discussed in relation to past and present use and to the potential for future development. Recent developments in remote sensing, photogrammetric and computer-assisted techniques for resource survey and mapping applications are also considered and illustrated.

ROBERTSON, R. A. and STOVE, G. C. A remote sensing methodology for peat resource survey. *Proc. 6th Int. Peat Congr., Duluth, U.S.A.*, 1980, 84-87.
A remote sensing strategy, designed to improve the speed and accuracy of peat resource, land-use and vegetation surveys, has been developed and evaluated. Results show that a photogrammetric approach combined with the systematic acquisition, enhancement and interpretation of both aerial and space imagery is particularly effective in mapping and classifying large areas and for monitoring changes in terrain and other features.

SCOTTISH AGRICULTURAL COLLEGES and the SCOTTISH AGRICULTURAL RESEARCH INSTITUTES. Trace element deficiencies in ruminants. Edinburgh, Scottish Agricultural Colleges, 1982.

SHARP, B. L. Laser remote sensing of atmospheric pollutants. *Chemistry in Britain*, 1982, **18**, 342-350.

A general review of laser remote sensing of atmospheric pollutants, aimed at the non-specialist reader, is presented. The various techniques are described and their relative merits discussed.

†SHIPLEY, B. M. Land use capability map of Crieff (Sheet 47). Scale: 1:63 360. Southampton, Ordnance Survey, 1981. £1.20. Folded £1.50.

SIMONSWOOD MOSS: report of survey and evaluation for Merseyside County Council. Aberdeen, Dept. Peat and Forest Soils, Macaulay Institute for Soil Research, 1982.

1185 SINCLAIR, A. H. A comparison of electroultrafiltration and quantity/intensity measurements of soil potassium with its uptake by ryegrass in Scottish soils. *Plant and Soil*, 1982, **64**, 85-92.

Potassium was extracted from soils by applying an external electric potential to aqueous soil suspensions, and collecting the leachates containing the extracted nutrients by ultrafiltration. Potassium extracted within 10 minutes correlated closely with the equilibrium K-activity ratio for soils within the same series, but the slope of the linear regression depended on soil K buffer capacity. Potassium extracted with neutral 1 M ammonium acetate correlated more closely with K uptake by ryegrass than either EUF or quantity/intensity measurements.

SINCLAIR, A. H. Manganese deficiency in spring barley. *Technical Note No. 18 CH. North of Scotland College of Agriculture*, 1982.

1199 SMITH, B. F. L. and BAIN, D C. A sodium hydroxide fusion method for the determination of total phosphate in soils. *Comm. Soil Sci. Plant Anal.*, 1982, **13**, 185-190.

A method has been devised for inexpensive routine determination of total phosphate in soils. The results obtained compare very favourably with published results for standard rocks and also with analyses by established methods for Scottish soils.

1181 SMITH, B. F. L., PATERSON, E. and MITCHELL, B. D. Trimethylsilylation of commonly occurring primary and secondary minerals in soils. *J. Soil Sci.*, 1982, **33**, 115-124.

The ease with which rocks weather to form soil is related to the arrangement of silica units in the structures of their component minerals. In an attempt to quantify this arrangement, organic (trimethylsilyl) derivatives of primary and secondary minerals occurring in soils have been prepared, separated and identified. Results indicate that: (a) of the primary minerals the ferromagnesian are the most susceptible to acid attack, (b) inorganic gels, particularly those high in alumina, are reactive and (c) crystalline clay minerals, especially kaolinite and illite, are relatively stable.

1159 SPARLING, G. P. Heat output of the soil biomass. *Soil Biol. Biochem*, 1981, **13**, 373-376.

The heat evolved from a soil can give a good indication of the overall level of microbial (biomass) metabolism and rates of substrate decomposition. Laboratory measurements of heat output and respiration rates showed that in many soils up to 80% of the organisms were inactive and dormant. The organisms could be stimulated into activity by adding glucose and the heat output and respiration increased nearly 20 times. The heat output from the amended soils was generally related to the size of the biomass, but two soils showed almost double the heat output of the others, indicating differences in the biomass metabolism between groups of soils

1182 SPARLING, G. P., CHESHIRE, M. V. and MUNDIE, C. M. Effect of barley plants on the decomposition of ^{14}C-labelled soil organic matter. *J. Soil Sci.*, 1982, **33**, 89-100.
The organic matter content is important in maintaining the structure and fertility of soils. Certain crops, particularly grasses, have been shown to increase organic matter levels and to improve soil structure. In this work ^{14}C-labelling was used to study the effect of living barley plants on the rate of decomposition of the organic matter. The barley plants decreased the losses of organic matter as CO_2, which was partly explained by the uptake of soluble organic components by the roots.

1165 SPARLING, G. P., ORD, B. G. and VAUGHAN, D. Changes in microbial biomass and activity in soils amended with phenolic acids. *Soil Biol. Biochem.*, 1981, **13**, 455-460.
Phenolic acids are common in soils and can inhibit or stimulate plant growth, depending on the concentration of the acids. Some plants are more sensitive than others to phenolic acids and this could be important in crop rotation sequences. Phenolic acids were added to soils from fallow, peas, barley or potato plots: the additions caused a rapid increase in microbial biomass and respiration. By 28 days the microbes had degraded virtually all of the phenolic acids. Soil from the potato plot was initially faster at degrading the acids than the other crops suggesting that potatoes had stimulated the growth of phenolic-decomposing organisms.

1180 SPARLING, G. P., CHESHIRE, M. V., MUNDIE, C. M. and MURAYAMA, S. Transformation of ^{14}C-labelled glucose in sterilized soil inoculated with selected microorganisms. *Rev. Ecol. Biol. Sol.*, 1981, **18**, 447-457.
The contribution of various microbial groups to the synthesis of the polysaccharide component of soil organic matter was investigated. Selected organisms were grown in soil sterilized by γ-irradiation or autoclaving and were fed with ^{14}C-glucose. The polysaccharides synthesized by yeast contained a high proportion of mannose and xylose, whereas those of filamentous fungi contained a high proportion of galactose and mannose. Rhamnose was synthesized by the bacterium *Azobacter chroococcum* but not by other bacteria. Some glucose became incorporated in the soil organic matter even in the absence of microorganisms, probably because of slow chemical interactions, but the proportion incorporated was very small.

1203 STOVE, C. Digital thermal image of Aberdeen Harbour. *Int. J. Remote Sensing*, 1982, **3**, 109-111.

STOVE, G. C. Land cover and resource surveys in Grampian: progress and results to date. *Proc. Seminar Remote Sensing and Strategic Planning, Aberdeen*, 1981, 11-40.
The development of remote sensing at the Macaulay Institute is described and illustrated using the results of a project, commissioned by the Grampian Region Department of Physical Planning, to produce a land use map of the Buchan area in N.E. Scotland from LANDSAT satellite imagery. Recent progress in a joint experiment with RAE Farnborough on multi-temporal classification of land cover types in the Grampian Region is also reviewed.

1227 STOVE, G. C. and RITCHIE, P. F. S. A hybrid photogrammetric and image. processing system. *Photogrammetric Record*, 1982, **10**, 629-644.
The development of the Macaulay Automated Photogrammetric System (MAPS) is described. Interaction with a software-based image processing system provides a unique photogrammetric and image processing system (MAPIPS). With the addition of an Aviotab TA plotting table, a tri-axis locator and PRI 1 interface, the current status of MAPIPS is discussed. Examples are given of the use of this system for natural resource surveys.

STOVE, G. C., BIRNIE, R. V., THOMSON, R. L. (Dept. Physical Planning, Grampian Regional Council, Aberdeen) and McKAY, D. A. P. An experimental land use map for regional planning based on interpretation and classification of multi-temporal LANDSAT data. In: *Geological and Terrain Analysis Studies by Remote Sensing.* Edited by J. A. Allan and M. Bradshaw. Reading, Remote Sensing Soc., 1981, 91-109.
The results of a collaborative investigation into the potential value of LANDSAT MSS data for annual regional land use surveys are presented. July and September, 1979, imagery for the Buchan area of the Grampian Region were used. Seven land use/land cover categories were tested on the IDP3000 system at RAE Farnborough and the optimum multiband classification for each category was identified. A preliminary land use map for the Buchan area was produced by manual interpretation of rectified Band 5 (visible red) July imagery. Development of an interactive digital image processing system (MAPIPS) in the Macaulay Institute has resulted in the production of a cereal map for part of the Buchan area in 1979. This has an areal accuracy of some 93% ON-going development of the MAPIPS system should result in the production of an automated land use map for the Buchan area.

THOMAS, J. M., BELCHER, R. and WEST, T. S. *eds.* Recent advances in analytical chemistry: Proc. Royal Society Discussion Meeting, December, 1981. London, Royal Society, 1982.

URE, A. M. The analysis of soils, geological materials and natural waters by spark source mass spectrometry. *Proc. 6th Czechoslovak Spectr. Conf., Nitra,* 1980, 61-76.
The Spark Source Mass Spectrometric (SSMS) methods in use at the Macaulay Institute for Soil Research are briefly outlined and the comprehensive element coverage and the high sensitivity of the technique compared with other spectrochemical methods. Illustrative applications of SSMS to the analysis of soils and geological materials are presented and the use of a 62-element soil fingerprint described. The analysis of natural waters by SSMS following preconcentration by cementation of aluminium powder is also discussed.

1213 URE, A. M. Comprehensive quantitative analysis by spark source mass spectrometry: a technique on the brink. *Trends in Anal. Chem.,* 1982, **1**, 314-317.
Spark Source Mass Spectrometry (SSMS) and its capabilities for comprehensive analysis are briefly reviewed. The potential of the technique and its limitations are discussed and it is suggested that the crucial development required to assure the future of SSMS is a simultaneous multi-element electronic detection system. Some possible methods for achieving this are indicated.

URE, A. M. and BERROW, M. L. The elemental constituents of soils. In: *Environmental Chemistry. Vol. 2. Chapter 3.* Edited by H. J. M. Bowen. London, Royal Society of Chemistry, 1982, 94-204.
A comprehensive account of the properties and concentrations of the elemental chemical constituents of soils is presented in a review of the literature based on over 1000 references. A brief discussion of the geochemistry and biological significance of the elements in a soil context is given together with tabulated mean and ranges of soil contents for 68 elements compiled from the recent literature.

1210 URE, A. M. and WELCH, K. H. The detoxification of pot ale and other copper-rich effluents by cementation of copper on aluminium metal. *J. Sci. Fd. Agric.,* 1982, **33**, 711-714.
A method is described for the removal of copper from copper-rich effluents such as pot ale, a waste product from malt whisky distillation in copper stills. This method makes use of cementation on aluminium metal obtained cheaply from aluminium beer cans and could be of potential practical value for the detoxification of copper rich effluents such as pot ale and pig slurry before disposal to agricultural land. Traces of silver, gold and platignum have been found in pot ale by a spark source mass spectrographic technique which also uses a cementation procedure to preconcentrate trace elements on to aluminium metal.

1208 VAUGHAN, D. and ORD, B. G. An *in vitro* effect of soil organic matter fractions and synthetic humic acids on the generation of superoxide radicals *Plant and Soil*, 1982, **66**, 113-116.
Soil organic matter fractions, particularly humic acid, enhance the activity of xanthine oxidase, an enzyme which produces the superoxide radical. Because this radical has been shown to be injurious to living tissues, it may be assumed that soil organic matter can have an undesirable effect on plant metabolism. However, these soil organic matter fractions also enhance the activity of superoxide dismutase, an enzyme involved in the destruction of the superoxide.

1187 VAUGHAN, D., DeKOCK, P. C. and ORD, B. G. The nature and localisation of superoxide dismutase in fronds of *lemna gibba* L, and the effects of copper and zinc deficiencies on its activity. *Physiol, Plant.*, 1982, **54**, 253-257
Superoxide dismutase, a metallo-protein containing copper and zinc, which protects aerobic organisms against oxygen toxicity, has been demonstrated in *lemna gibba*. When *lemna* fronds were grown in a medium deficient in zinc, the amount of superoxide dismutase formed was decreased relative to that in fronds grown in zinc-sufficient media. Copper deficiency, however, appeared to have no effect on the amount of enzyme formed. The growth inhibitor abscisic acid inhibited the growth of *lemna* fronds and increased both superoxide dismutase activity and zinc content, whereas the growth promotor benzyladenine enhanced growth but had little effect on the enzyme or on zinc content of the fronds.

1167 VAUGHAN, D., JONES, D. and ORD, B. G. An *in vitro* effect of Dazomet on phenolase activity in exudates of *Sclerotinia sclerotiorum*. *Trans. Brit. Mycol. Soc.*, 1981, **77**, 423-425.
Previous work has shown that the soil fumigant Dazomet inhibits phenolase activity in exudates formed on developing sclerotia of the plant pathogen *Sclerotinia sclerotiorum*. This paper compares the effects of the copper complexing agent sodium diethyldithiocarbamate and other chelating agents with those of Dazomet. It is concluded that Dazomet inhibits phenolase activity by forming a Cu-S covalent bond thus "poisoning" the enzyme.

1184 VERBEEK, A. A., MITCHELL, M. C. and URE, A. M. The analysis of small samples of rock and soil by atomic absorption and emission spectrometry after a lithium metaborate fusion/nitric acid dissolution procedure. *Anal. Chim. Acta.*, 1982, **135**, 215-228.
A method is described for the determination of the total contents of ten major and minor elements in small (50-100 mg) rock or soil samples. Samples are dissolved in nitric acid following a lithium metaborate fusion procedure and the analysis is performed by atomic absorption or emission spectrometry using a nitrous oxide/acetylene or air/acetylene flame.

WEST, T. S The atomic spectroscopy of biosignificant trace elements in soils in relation to plant and animal nutrition. *Proc. European Society for Nuclear Methods in Agriculture, XII*, 1981, 46-58, and *Bunseki Kagaku (Japan Analyst)*, 1981, **30**, 103-115.
The trace elements B, Co, Cu, Fe, Mn, Mo and Zn have been shown to be essential for the growth of plants and, with the exception of B, for animals. Seven other elements, Cr, Ni, Se, Si, V, Br and I are biofunctional though not essential. The roles played in plants by these elements are reviewed and the effects produced by deficiency. The analytical problem is surveyed from the viewpoint of the range of these elements in soils, their forms of occurrence and the influence of factors that affect their uptake by plants. Finally, the means by which plant uptake is simulated to permit preventive or corrective measures to be made are discussed and the role played by some of the techniques of analytical atomic spectroscopy.

1215 WEST, T. S. Biosignificant trace elements in soils. *Anal. Proc.*, 1982, **19**, 436.
The role of biosignificant trace elements in soils in relation to plant and animal nutrition as revealed by the techniques of atomic spectroscopy is described.

1212 YOUNG, S. D., BACHE, B. W. and LINEHAN, D. J. The potentiometric measurement of stability constants on soil polycarboxylate-Cu^{2+} chelates. *J. Soil Sci.*, 1982, **33**, 467-475.
Stability constants have been determined for complexes between copper and soluble soil organic matter, using pH measurements alone, and in combination with ionic copper measurements. The distribution of copper between ionic and complexed forms in soil solution has been calculated as a function of pH and soluble organic matter level.

1171 YOUNG, S. D., WELCH, D., BACHE, B. W. and ANDERSON, H. A. Analysis of the potentiometric titration of natural and synthetic polycarboxylates. *J. Soil Sci.*, 1981, **32**, 579-592.
The dissociation of carboxylic acids in soil humus fractions and in polymaleic acid (a synthetic humus analogue) has been studied by potentiometric titration. The results show that humus acids exhibit a greater degree of preferential COOH-group clustering compared with a more random group-distribution on the synthetic molecule. Nevertheless the polymaleic acid seems a reasonable representation of humus acids in that its acid characteristics lie between that of a humic and fulvic acid.

AGRICULTURAL RESEARCH INSTITUTES IN GREAT BRITAIN

The research programmes of the following agricultural research institutes supported by public funds are co-ordinated by the Agricultural Research Council. These institutes generally publish annual reports or periodical reports summarizing the research work that is in progress. Full details can be obtained from the secretaries of the institutes concerned.

ARC Institutes

Animal Breeding Research Organisation	King's Buildings, West Mains Road, Edinburgh, EH9 3JQ.
Institute of Animal Physiology	Babraham, Cambridge, CB2 4AT.
Institute for Research on Animal Diseases	Compton, Newbury, Berks, RG16 0NN.
Food Research Institute	Colney Lane, Norwich, NR4 7UA.
Meat Research Institute	Langford, Bristol, BS18 7DY.
Poultry Research Centre	King's Buildings, West Mains Road, Edinburgh, EH9 3JS.
Letcombe Laboratory	Letcombe Regis, Wantage, Oxfordshire, OX12 9JT.
Weed Research Organisation	Begbroke Hill, Sandy Lane, Yarnton, Oxford, OX5 1PF.

State-aided Institutes (Scotland)

Animal Diseases Research Association	Moredun Institute, 408 Gilmerton Road, Edinburgh, EH17 7JH.
Hannah Research Institute	Ayr, KA6 5HL.
Hill Farming Research Organisation	Bush Estate, Penicuik, Midlothian, EH26 0PH.
Macaulay Institute for Soil Research	Craigiebuckler, Aberdeen, AB9 2QJ.
Rowett Research Institute	Bucksburn, Aberdeen, AB2 9SB.
Scottish Institute for Agricultural Engineering	Bush Estate, Penicuik, Midlothian, EH26 0PH.
Scottish Crop Research Institute	Invergowrie, Dundee, DD2 5DA. and Pentlandfield, Roslin, Midlothian, EH25 9RF.

State-aided Institutes (England and Wales)

Animal Virus Research Institute	Pirbright, Woking, Surray, GU24 0NF.
East Malling Research Station	East Malling, Maidstone, Kent, ME19 6BJ.
Glasshouse Crops Research Station	Worthing Road, Rustington, Littlehampton, Sussex, BN16 3PU.
Grassland Research Institute	Hurley, Maidenhead, Berks, SL6 5LR.
Houghton Poultry Research Station	Houghton, Huntingdon, PE17 2DA.
John Innes Institute	Colney Lane, Norwich, NOR 7OF.
Long Ashton Research Station	Long Ashton, Bristol, BS18 9AF.
National Institute of Agricultural Engineering	Wrest Park, Silsoe, Beds., MK45 4HS.
National Institute for Research in Dairying	Shinfield, Reading, Berks., RG2 9AT.
National Vegetable Research Station	Wellesbourne, Warwick, CV35 9EF.
Plant Breeding Institute	Maris Lane, Trumpington, Cambridge, CB2 2LQ.
Rothamstead Experimental Station	Harpenden, Herts., AL5 2JQ.
Welsh Plant Breeding Station	Plas Goggerddan, Aberystwyth, Dyfed, SY23 3EB.
Wye College, Department of Hop Research	Ashford, Kent, TN25 5AH.

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