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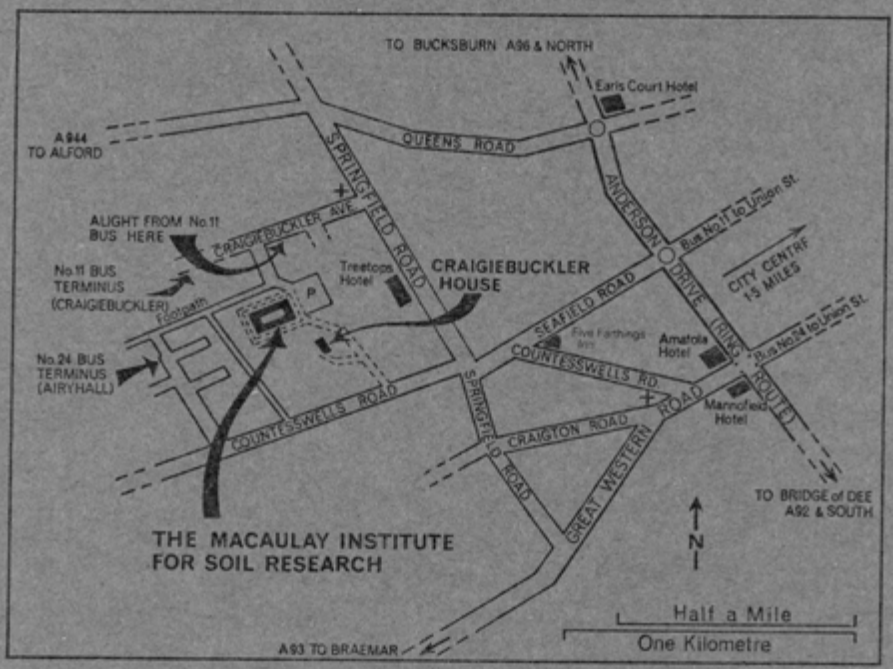

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The main part of this report covers the period from 1st October, 1980, to 30th September, 1981. The staff list is that current in November/December, 1981, and the Introduction is similarly updated. The report was published in May, 1982.

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THE MACAULAY INSTITUTE FOR SOIL RESEARCH

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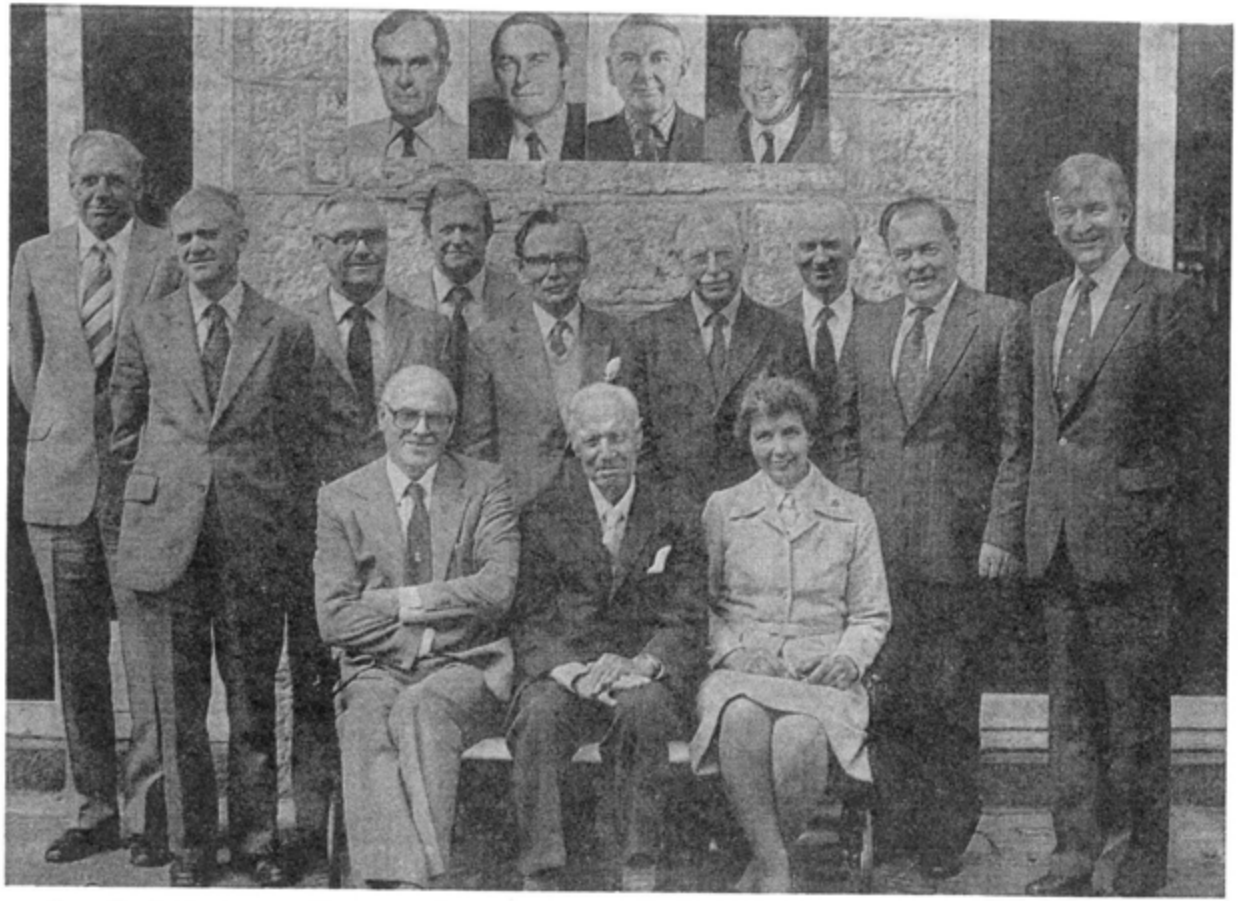

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1980 - 81

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J. A. Hipkin, B.Sc.
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Dr A. B. Stewart, C.B.E., M.A., B.Sc., Ph.D., LL.D., C.Chem., F.R.S.C., F.R.S.E.—deceased 27/2/81.

Dr R. L. Mitchell, B.Sc., Ph.D., C.Chem., F.R.S.C., F.R.S.E.

Dr E. G. Williams, B.Sc., Ph.D.

VISITING RESEARCH WORKERS

G. Black, Department of Peat and Forest Soils (Memorial University, Newfoundland).

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Dr J. M. Criado Lucque, Department of Mineral Soils (Universidad de Sevilla, Spain).

*Miss S. Fraser, Department of Soil Fertility, M.O.D. Research Student.

R. Gomez, Department of Spectrochemistry (Chemistry Department, Aberdeen University).

*M. J. Hepher, Department of Soil Fertility, A.R.C. Research Student.

Mr C. J. Koch, Department of Spectrochemistry (Royal Vet. and Agricultural University, Copenhagen).

*Lau, Chau Ming, Department of Spectrochemistry, Research Student.

Dr R. Lee, Department of Soil Fertility (DSIR Soil Bureau, Lower Hutt, New Zealand).

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A. N. Pandey, Department of Spectrochemistry (Institute of Petroleum Exploration, Oil and Natural Gas, Government of India).

*Miss F. Proctor, Department of Plant Physiology, DAFS Research Student.

*M. F. Proe, Department of Peat and Forest Soils, NERC/CASE Research Student.

Miss M. M. Ron, Department of Plant Physiology (Universidad Nacional del Sur, Argentina).

C. A. Shand, Department of Spectrochemistry, Scottish Hospitals Endowment Research Trust Fellowship.

*B. Thornton, Department of Plant Physiology, A.R.C. Research Student.

Dr M. A. Vicente Hernandez, Department of Mineral Soils (Centra de Edafologia y Biologia Applicado, Salamanca, Spain).

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*P. Wilson, Department of Spectrochemistry, A.R.C. Research Student.

*S. D. Young, Department of Soil Fertility, A.R.C. Research Student.

*Ph.D. Student.

CONTENTS

INTRODUCTION

T. S. West

The performance of a scientific research institute can be judged by several criteria, but the principal ones are undoubtedly the quality and quantity of the research it does and, equally important, particularly in times of economic difficulty, the relevance of its research to the community which finances it. Judged by both criteria the Institute has had another successful year during the period 1980-81.

The number of publications was 80 which is considerably less than the 92 of the period covered by the previous report. By this index alone we would seem to have contributed less to the accumulation of scientific knowledge during 1980-81 than in the two previous periods although still considerably more than in any previous year. However, it must be borne in mind that the time required to get papers through the publishing process varies greatly, as does the speed with which scientists sit down to write up their research. Additionally, there has had to be a significant decrease in staff within the Institute over this period of time. This decrease has been most marked amongst assistant scientific officers, *e.g.* those who are responsible for supplying data from ongoing field and laboratory experiments, from analytical service laboratories and from statistical and computational services. The decrease in number of publications may, therefore, be less significant than appears superficially. Their quality is, however, as high as, or higher than, before and many of them have aroused considerable interest amongst other scientists, *e.g.* on the basic side, those proposing significant new ideas on the development of podzols within the soil profile, and new work on monitoring the fate of bioessential trace elements passing from the soil to the plant. Similarly, papers relating to new ideas on the surveillance from space of terrain features and changes on the land surface, and to new developments in the major and minor mineral element nutrition of forage, crops and trees have been well received, as have those relating to new insights on the biological weathering of rocks and the composition and behaviour of organic matter in soil. On the more applied side there are very significant publications from the Soil Survey teams on soil and land-capability-for-agriculture maps for several agriculturally important areas of Scotland as well as the first peat and terrain category map of Lewis and North Harris to be produced principally from satellite data by the Peat Survey team. Other papers discuss nutrient requirements for growing herbage on peat, evidence for crop responses to added sulphate fertilizer, interactions between phosphate and aluminium in the response of barley to soil acidity and fertilizer recommendations for the North of Scotland area.

It will be seen, therefore, from an examination of the publications list for 1980-81 that not only has valuable work been done on the long-range basic aspects of soil research, but that there is considerable direct relevance to farming problems in Scotland, particularly northern Scotland.

Much of the work described in the reports of the individual departments has not yet been published in the scientific literature or is in the process of being prepared for publication. Here again it will be seen that during the year the staff have made considerable contributions to scientific knowledge, to agriculture and to the community.

Trace Element Categorisation of Soils

In northern and indeed in other parts of Scotland, many soils are derived from acid igneous rocks such as granite or from sandstones. These rocks tend to have lower than average contents of bioessential trace elements such as cobalt, copper, molybdenum, manganese, selenium and zinc and the soils tend, in turn, to show low plant availability of these and other elements. The distribution of these soils can, of course, be found from a study of the soil maps and memoirs produced by the Soil Survey Department, but this information is not always available in an easily assimilated form. As a contribution to overcoming this problem we have supplied information on the total trace element contents of the B horizons of about 600 soil profiles to the COSAC-SARI Trace Element Study Group to serve as a preliminary indication to College advisory staff of which Soil Associations are likely to show, for instance, cobalt or copper deficiencies or induced copper deficiency due to excessive relative amounts of molybdenum. For example, there is a high risk of cobalt deficiency in livestock grazing on herbage grown on the following soil associations: Ardvanie, Corby, Countesswells, Cromarty, Dalbeattie, Eckford, Fraserburgh and Kindeace and of copper deficiency in the Ardvanie, Cadboll, Corby, Countesswells, Fraserburgh and Kindeace Associations. Unusually high amounts of molybdenum may induce further copper deficiency problems in areas of the Darleith, Dreghorn, Ettrick, Rowanhill, Sourhope, Strichen, Tarves, Thurso and Yarrow Associations. It should be stressed that these are predictive possibilities rather than actualities. Local management practices can considerably influence matters. For example, at higher soil acidity most of the bioessential elements become more plant available, but the reverse is true for molybdenum and selenium. Soils that have been subject to impeded drainage for some time may show higher availability patterns while, except for molybdenum and selenium, recently limed soils may show lower than usual availabilities. It will also be seen from Section 7 that, at least for manganese, soil compaction has a role to play in plant availability and the point is made there that soil physical conditions and management practices should be taken into consideration, as well as chemical analyses, in assessing nutrient supply to crops.

The Soil Associations mentioned above take their names from the places where they were first characterised, but since they reflect the nature of the parent materials from which the soil was derived rather than the place name, they can be found in many other localities in Scotland. Their

occurrence can be seen by examination of the 1:63,360 or 1:50,000 scale soil maps published by the Institute, or by reference to the regional soil survey memoir for the districts concerned. The latter give very detailed information on most aspects of soil composition and potential land use.

Selenium deficiency which is responsible for muscular distrophy, or white muscle disease, in livestock is also widespread in Scotland. To provide advice on this element, over 30 topsoils from various parts of Scotland were analysed. Those from the Corby and Dreghorn Associations, both of which are developed on parent materials of sand and gravel, are particularly deficient and are most likely to be associated with selenium deficiency problems in animals. Difficulties may also be encountered with some of the other Associations examined, *e.g.* Countesswells, see Section 3. It will also be seen from Section 7 that extensive analysis of herbage and the soils on which it is grown is being undertaken and that attempts are being made to develop a predictive capacity. In this connection it should be noted that these studies have only recently become possible as a result of strategic research on the evolution of new sufficiently sensitive spectrochemical and electro-analytical techniques for selenium in this Institute. Several of these have been mentioned in earlier Annual Reports and their application to field work is one which now gives us considerable satisfaction.

Iron Ochre in Drainage Systems

Although the Institute does not undertake research or directly provide advice to farmers on drainage problems, which are primarily the concern of the advisory services of the Colleges of Agriculture, it is becoming involved with those aspects that are related to the inherent nature of the soil profile (Soil Survey), the physical nature of the soil (Soil Fertility) and, more specifically, the microbiological and mineralogical aspects of the blockage of field drains. It is in these areas that the Institute with its scientific, as opposed to engineering or farm management, expertise can make a worthwhile contribution to amelioration of these problems. Both the Departments of Mineral Soils (Section 1) and Microbiology (Section 6) are examining the nature of the deposited materials to establish their identity and subsequently to help pinpoint the reasons for blockage and thereafter to identify the areas at greatest risk and methods for prevention or minimisation. Section 1 discusses studies of the ochreous deposits and reveals the principal iron oxyhydroxide mineral to be goethite. Drainage water in the profile examined contained 10-25 parts per million of reduced iron salts which upon oxidation yielded the undesired ochreous deposit. Meanwhile, the microbial population of the soil is thought to be involved *e.g.* in the oxidation/reduction process, and in Section 6 on Microbiology a survey of the occurrence of iron ochre and white microbial deposits in field drainage systems is shown in map form. The absence of information on this map does not imply that field drain blockage does not occur in the area and may, in some respects, be as characteristic of the concern of conscientious farmers in reporting persistent blockage problems as of the nature of the soil in the areas mentioned on the map. On the information presently available, there do, however, appear to be some regional soil relationships.

Fertilization of Winter Barley

In line with current interest in the relative merits of autumn-sown (winter) barley and spring-sown barley we have paid considerable attention in recent years to relationships between yield and fertilization regimes. In Section 7 it will be seen that the previous report that "winter" barley (Igri) needs more nitrogen fertilizer than "spring" barley (Golden Promise) has been confirmed again, at least as far as these varieties are concerned. Five trials on spring barley required 110-120 kg/ha N for maximal yields, whereas the winter barley required 150-170 kg/ha in three trials with three others still showing a linearly increasing response at 160 kg/ha. In addition, whereas over 50 experiments on spring barley in recent years gave an average yield of 6·5 t/ha of grain dry matter, this year winter barley on one site ploughed out of a grass-clover ley yielded 8·2 t/ha under carefully managed conditions (early sowing and good weed and disease control).

Two other factors of particular interest emerge from the work on barley. The higher yield potential of winter barley at higher nitrogen levels arises from the considerably longer period *ca.* 20-30 days, over which tiller development takes place with autumn sown "Igri." With spring-sown Golden Promise all the fertile tillers appeared over a *ca.* 10 day period. Thus there is a greater tendency for uneven ripening to occur with winter barley and the farmer has to judge whether to harvest the crop early with a larger proportion of unripe grain, necessitating higher drying costs, or to leave the crop to ripen fully with consequent risk of losing over-ripe grain. In many cases other considerations may well dictate early harvesting, however. The other interesting feature that emerged was that, in April, winter barley had a higher carbohydrate content than spring barley, though eventually both reached similar contents at their harvesting points.

Other experiments on barley (Section 7) showed that soil (water) pH values below 6·2, *e.g.* 5·6, still gave good yields in the absence of other growth limiting factors and this year, for the first time in our experiments under northern Scottish conditions, direct drilling of barley produced higher yields than traditional cultivation methods. It has also been shown that even 25 years after application, copper sulphate (or oxychloride) is still producing higher yields of spring barley (this year also winter barley) than the untreated copper-deficient soil. These results show that for copper, trace-element fertilization of deficient soils is a practical proposition in the sense that its effects on plant growth are long lasting. This is not the case for some other bioessential trace elements, *e.g.* Co and Se, where the beneficial effects disappear after a much shorter period of time. It should also be said, whilst discussing copper, that in general the copper content of cereals and grasses is not markedly raised at maturity by moderate copper amendment of the soil. It is probable that with increased growth efficiency carbohydrate accumulation "dilutes" the higher copper concentration that might otherwise have been seen in the grain. As a result, copper amendment of soils is not generally to be thought of as a solution to problems of serious copper deficiency in grazing livestock.

Whilst discussing the effects of the *moderate* additions of copper to

deficient soils it is perhaps appropriate here to refer to some of our other experiments in which we are investigating the long-term effects of adding *excessive* amounts of copper and other trace elements to soils, *e.g.* the deposition of copper-rich pot ale wastes from distilleries, pig slurries from intensive animal production units and copper and other trace element rich sewage sludges.

Problems of Contaminated Soils

In the 45th and 46th Annual Reports we mentioned electron paramagnetic resonance experiments that showed that copper occurred in a plant unavailable form as porphyrin complexes in certain soils on which distillery wastes had been deposited for many years. Since porphyrins are molecular species that occur frequently in plant matter and are resistant to decomposition, this suggested that the addition of material rich in plant remains, *e.g.* peat, might render excessively high levels of copper in soils relatively harmless to plant growth. A collaborative experiment between the Departments of Soil Organic Chemistry and Spectrochemistry described in this year's report has made a preliminary examination of this possibility in a series of pot experiments using lucerne as the test crop. Two contaminated mineral soils were treated with various levels of peat, and lime was added to bring the pH up to 5·5 to counteract the acidity of the peat. At the lower end of the scale the copper content of the lucerne was reduced from 11·4 to 8·9 ppm and at the higher from *ca.* 50 ppm to 23 ppm Cu in the dry matter. Fairly large additions of peat were used in these experiments; further work is in progress. Other more fundamental work has shown that the copper complexes of more soluble organic molecules are effective in maintaining copper levels in the soil solution at pH values up to 7·5 in contrast to other bioessential trace elements such as cobalt, manganese and zinc which decrease in plant-availability by a factor of 5-10 fold in the range pH 5-7·5 due to their increasing adsorption on soil-particle surfaces as the pH is raised.

Meanwhile monitoring of soils and plants from two long-term experiments in which sewage sludges heavily contaminated with Cu, Cr, Ni and Zn were dispersed in the soil have continued. Ten years later all these elements are still present in extractable forms and there are still enhanced uptakes shown by clover and, to a lesser extent, grasses of Cu, Ni and Zn, but there is no evidence of increased uptake of Cr. The soil levels of all four elements and Cd and Co have fallen slightly between the years 1972, 1976 and 1981, but high levels still persist, particularly of Cu and Zn.

Nutrient Recycling in Forest-Soil Systems

About 10% of the land surface is forested and there is, of course, a continuing debate not only on the relative merits of land use for agriculture and forestry, but also on the utilization of fertilizers for promoting tree growth. The limited amount of work we have been able to do on the biogeochemistry of forested ecosystems has, this year, provided more useful evidence towards an understanding of the complex nutritional factors that control tree growth under present management systems. As a result, a

considerable contribution has been made to the search for improved sylvicultural practices that are less dependent on heavy inputs of fertilizers and energy. This work is also leading to a much better understanding of soil-plant relationships and soil genesis under conditions of limited nutrient supply and will increasingly allow a more significant contribution to be made to the study of nutrient cycling in other plant systems on marginal land, including the environmental consequences of possible increased atmospheric inputs.

In established forests, a considerable proportion of the demand for nutrients for new growth is met by translocation from older tissues including foliage particularly, and branches to a smaller extent, prior to death. In a closed canopy pine growth, only 69 kg of the total 138 kg/ha of N required for new growth came from root uptake. Similarly translocation provided 57 and 55% of the annual requirement of P and K respectively. On the other hand, younger trees still expanding their crowns, *i.e.* before canopy closure, are less well able to recycle so that the nutrient demands made on soil reserves by 10-year-old trees are 2-6 times greater than those made by 40-year-old trees. This reduction in demand as canopy closure occurs means that there should be a much lower need for fertilization in general, though the development of a mor humus layer will subsequently reduce the availability of nitrogen. One consequence of this is that the formulation of forest fertilization requirements on the basis of the usual foliar analysis needs to be qualified by the age and development of the trees. Studies on forest nursery practice have shown that even though the optimum pH for coniferous seedlings is as low as 4·5-5·0 there is an increasing need to prescribe lime for nurseries that have been in production for many years.

Acidification

The problems raised by the occurrence of greater acidity of water collected beneath old pine than in that beneath young pine, spruce, larch, birch or heather are now more fully understood. Our recent experiments have shown that there is a marked neutralization of rainwater as it passes through the ground vegetation layer beneath the trees. The acidity is, however, replaced as it passes through the humus layer only to be largely neutralised again at depth in the mineral soil. However, the results do indicate that the water is more acid beneath pine, particularly old pine than beneath other types of vegetation.

Work on acid-rain this year reveals that, whilst it is unlikely to damage vegetation or harm any but the most sensitive soils, it is likely to acidify streams and lakes in areas of thin soils or resistant geology where, respectively, the residence time of the water in the soil is low or the weathering reactions are slower than average.

Microbiological Weathering and Nitrogen Fixation

The interdisciplinary attack of the Departments of Mineral Soils and Microbiology with their respective expertise in the physical and biological sciences on one of the earliest stages of soil formation, *viz.* the biological weathering of rocks, has continued to yield significant results and, as

mentioned earlier, to attract widespread interest. As discussed in Section 1 of this Report, lichen-weathering typically involves dissolution of minerals at grain surfaces and boundaries by chelating acids exuded by the lichen, preferential extraction of Al, Fe and Mg leaving silica-rich deposits, precipitation of poorly ordered weathering products and accumulation of relatively insoluble organic salts—mainly oxalates. The interest aroused by this work is referred to in Section 6. Requests for further information have come from scientists concerned with lichens on Mayan ruins in Central America, on ancient monuments in Spain and rock outcrops in the Antarctic. Other workers have reported similar observations on lichens associated with 800-year-old bones from an archaeological site in the High Arctic.

In the 50th Annual Report reference was made to possible nitrogen fixation by soil bacteria associated with wheat roots. Nitrogen balance and nitrogen isotope (^{15}N) experiments have now been done. These show that there is little significant useful fixation under temperate conditions despite the earlier experiments that appeared to show a definite benefit for one specific strain of wheat. The main limitation to useful nitrogen fixation appears to be a shortage of nutrient carbohydrate for the bacteria in the root zone. Plants grown with a supplement of extra carbohydrate in the soil showed nitrogen fixation both by aerobic, microaerophylic and facultative anaerobic bacteria and the transfer of the fixed nitrogen to the above-ground parts of the plant. Indirect evidence suggests further that the microbiologically fixed nitrogen did not become available to the plant until death and lysis of the microbes had occurred. In view of these results, further work on nitrogen fixation by bacteria associated with wheat roots is being discontinued at the present time.

New Test for Assessing Fertility of Peat

Other microbiological work is aimed at assessing the stability of the soil aggregates that are responsible for the tilth structure of the soil, particularly in relation to the influence of soil polysaccharides. An interesting direct relationship has also been discovered between the size of the microbial biomass in peat and the quantity of mineralisable nitrogen it contains, *i.e.* its inherent fertility. This discovery, which arose out of an investigation of a substrate-amendment technique, may be useful in devising a means of rapid assessment of the relative fertility of different peats. It has also been established, Section 2, that the largest amounts of mineral nitrogen are produced from the fine fraction (0·005-0·05 mm) of the peat which was also found to contain 25-47% of the total nitrogen content of the peat.

New Evidence on Structure of Soil Organic Matter

It is commonly assumed that humic substances are highly aromatic in nature, *i.e.* that they contain carbon bound in cyclic ring structures. However, results obtained in our Department of Soil Organic Chemistry, and supported by new work in Australia, suggest that, whereas the newly

formed materials present in raw humus are highly aromatic in nature, increasing humification leads to decreasing aromaticity with the formation of increasing proportions of highly acidic aliphatic (open chain) material. Much of the organic matter in the soil solution is of this nature and its presence is instrumental in providing increased availability of some elements—particularly copper—to growing plants. Other work on soil organic matter using radio-active labelled material has shown why growing plants appear to reduce the rate of decomposition of organic residues in soil. About half of the reduction was accounted for by direct uptake of the labelled organic compounds in the added organic matter by the plant and its incorporation in the structural carbohydrates of the cell walls of the root though there was very little translocated above ground.

Calcium and Sulphur Deficiency Problems

Work in the Department of Plant Physiology, Section 5, describes further success in field experiments concerned with countering the effects of calcium deficiency in a number of crops, particularly carrots. The application of nitrate at intervals to counter restricted calcium uptake which is induced by ammonium ion occurring in wet soils has again demonstrated reduced incidence of cavity spot and sometimes considerably enhanced the crop yield. Fundamental studies on calcium uptake and transport in seedling plants have continued and the passive nature of calcium uptake has been confirmed. Other field work already mentioned in passing shows accumulating evidence, Section 7, that herbage crops, which are of considerable economic importance in Scotland, may well give worthwhile yield responses (10-15%) to added sulphate for cuts subsequent to the first one on soils that have a low sulphur status (*e.g. ca.* 5 mg S/kg soil-phosphate extract) but are otherwise fertile; there was virtually no response in the absence of nitrogen. Increased yields of *ca.* 10% were also observed for some potato crops grown on low sulphur (4 mg S/kg) soils. This sulphur response is interesting in view of the continuing use of sulphur-free fertilizers in areas where there is very little input of atmospheric sulphur oxides.

New Theory of Podzol Formation

At this stage it is perhaps appropriate to revert to another item briefly referred to earlier, *viz.* recent work in the Institute which sheds new light on the formation of podzolised soil profiles. The conventional view is that aluminium migrates or is washed out of the surface layers of the soil by complex formation with fulvic, and other organic acids formed by vegetation, to a lower region where by virtue of increased pH it redeposits once more. We have found, however, that the hydroxy aluminium silicate, imogolite and related allophanes are common constituents of Podzol B horizons. The conventional aluminium-fulvate theories cannot account for their occurrence there. A reassessment of the evidence suggests that aluminium migrates as a hydroxy aluminium silicate sol which can incorporate or "carry" substantial amounts of iron. The formation of humus-rich B horizons are explained by the deposition of colloidal organic matter on the allophanes previously deposited in the B horizons.

Remote Sensing of Spread of Bracken

The work of the Peat and Forest Soils Department, Section 2, highlights the growing importance and practical applications of peat and other terrain-resource inventories and surveys, not only in assessing their inherent value, but also in monitoring the impact of changes in land use and management practices. The production of the first satellite-based peat and other terrain-resource map of Lewis and North Harris has already been mentioned. An example in relation to land use and management stems from recent interest in the possible carcinogenicity (for ruminants) of bracken which, according to some sources is spreading considerably—possibly partly as a result of decreased interest in bracken eradication schemes. This has resulted in a survey using remote sensing to map and monitor the distribution of bracken in Scotland. The development of a program to extract bracken-specific information from the satellite tapes during the current season, with ground truth verification from the field team, will enable satellite tapes from previous years to be assessed so that the spread or redistribution can be assessed for a period of several years previously and, of course, monitored in the future.

Computing Power

There has been a further expansion of the Institute's "Data General" main-frame computer capability by the addition of a further 256 K bytes of core memory and a 192 M byte disk drive. The addition of the Query and Report Writer software for the Data General's INFOS file management system has greatly improved facilities for selecting, displaying and printing database records in the form of a report.

Progress has been made in the storage and retrieval of profile desorption data from the soils inventory sampling scheme and co-operation has been given in devising a coding form to assist in the computer storage of accumulated soil survey records.

At present 25 members of staff, other than the staff of the Department of Statistics, are authorised users of the main-frame computer.

Complete Soil and Land Capability Maps for Scotland

Lastly, in this survey of some aspects of the scientific research work of the Institute during the past year, the completion of the 1:250,000 mapping programme in April and May, 1981, should be mentioned. Legends have been compiled and the scribed maps have been submitted to the Ordnance Survey where work is on schedule for the production of colour proofs. The land-capability-for-agriculture (LCA) maps, which are to accompany the soil maps, are nearing completion and work is in hand on the writing of the seven descriptive handbooks which will accompany each set of soil and LCA maps. A revised land classification for agriculture system has been prepared but since it is not yet published is not used in this Report to avoid misunderstandings. It contains improved guidelines for classification, but most noticeably a provision of subdivision of the previous 7 classes of land use for agriculture. The new LCA system will be used in future Reports.

EVENTS AND PEOPLE

Sixth T. B. Macaulay Lecture

The Sixth T. B. Macaulay Lecture, entitled "Agricultural Research Counts" was delivered by Professor D. J. Finney, FRS, Director of the ARC Unit of Statistics of the University of Edinburgh, in the Marine Suite of the Amatola Hotel on 26th November, 1981. The lecture, which is presented as an Appendix to this Report, was attended by Institute staff and colleagues from the University, Rowett Research Institute and the COSAC-MISR Soils Liaison Group. The Chairman of the Council of Management, Professor T. C. Phemister, took the chair and the Director proposed the vote of thanks and presented the Scroll of Honour to Professor Finney.

It is with great regret that I have to record the death of Dr A. B. Stewart on 27th February, 1981. Dr Stewart was Director of this Institute —its third—from 1958 until 1968, and at the time of his death was a Fellow of the Institute.

His former colleague and friend Dr E. G. Williams, previous Deputy Director and also a Fellow of the Institute, has written an obituary notice for the 1982 Handbook of the Royal Society of Edinburgh of which Dr Stewart was a distinguished Fellow. With his permission I have used parts of that note for these paragraphs.

Dr Stewart was born near Tarland, Aberdeenshire, on 3rd November, 1904, and was educated at Robert Gordon's College. He graduated with 1st Class Honours in Chemistry from the University of Aberdeen in 1928 where he also took his PhD degree in 1932. He joined the Institute in the same year and became the first Head of its Department of Soil Fertility. In 1945 he became Deputy Director and in 1954 Professor of Agriculture at the University of Aberdeen. Four years later he returned to the Institute as its third Director, a post which he held with distinction until he retired in 1968. He was honoured by the award of the University's degree of LL.D. in 1971. He is survived by his wife who, as Alice Bowman, was the first Secretary of the Institute and by his son Donald, who is Assistant Secretary to the University of St Andrews,

Coming as he did from farming stock, Dr Stewart, with his grasp and training of the concepts of modern chemistry, was ideally placed with his small group of colleagues to play an outstanding part in the war years to promote effective and efficient use of scarce resources of the lime and fertilizers needed to supply food from its land to a nation under seige. He played an essential role during those years and in the almost equally troubled post-war years when the value of scientific farming became widely recognised. His influence extended beyond major nutrients into the trace element field with the aid of his Deputy Director, Dr R. L. Mitchell, who subsequently succeeded him.

Dr Stewart was very much a practical scientist and in his role as former Head of the Department of Soil Fertility and as Director of the Macaulay Institute for Soil Research he played a leading role in disseminating the results of scientific research in all branches of soil and the relevant plant sciences to the farming community in the UK and overseas. In this way he made a significant and widely appreciated contribution to agriculture generally as well as to this Institute in particular. Above all he was liked and respected by all his colleagues and although we mourn his loss it is with a feeling of warmth and appreciation that we remember him in this Institute.

Professor P. E. Weatherley, FRS, of the Department of Botany, Aberdeen University, who had been a member of our Council of Management since 1960-61 and served as the Convener of the Council's Staff Committee, retired from the Chair in September, 1981, and from his position as a representative of the University on the Council of Management. We are greatly indebted to Professor Weatherley for his long service and for the interest and encouragement he gave to us and our affairs so unstintingly. It is with grateful thanks for all he has done for us that we wish Professor and Mrs Weatherley a long and happy retirement.

Professor H. M. Keir, of the Biochemistry Department of the University, has succeeded Professor Weatherley as Convener of the Council's Staff Committee and Professor J. W. Parsons, of the Soil Science Department, has taken over as the new representative of the University of Aberdeen. Mr N. S. Thornton Kemsley has resigned as a representative of the North of Scotland College of Agriculture and has been replaced by Dr J. H. Topps, Head of the Division of Chemistry and Biochemistry at the College. It is also with regret that we lose Mr D. R. Johnston from the Council of Management upon his retirement as Director of Research at the Alice Holt Station of the Forestry Commission. We are, however, very pleased indeed to welcome Mr J. Maitland Mackie, Jr., as a newly co-opted member and thus strengthen our links with the local farming community and also through him with the Agricultural Research Council.

Dr R. O. Scott, Head of the Department of Spectrochemistry for the past 13 years, retired from the Institute after 42 years' service in August, 1981. Dr Scott came to the Institute as a research student in 1939 and has ever since made an invaluable contribution to the development of spectrochemical methods for the determination of trace elements in soils, plants and other agricultural materials. He was responsible with his former colleague, Dr R. L. Mitchell, for the introduction and perfection of group preconcentration techniques, *e.g.* the one based on a "cocktail" of 8-hydroxyquinoline-thionalide-tannic acid and aluminium ion as "carrier" which allowed most biosignificant trace elements to be determined in soil extracts and plants at levels below their normal detection or determination limit by the techniques subsequently used, *i.e.* emission spectrography, or atomic absorption spectrometry. His technique is still in use today, not only in this Institute but in many other trace-element laboratories. His method for the determination of iron described in his first publication (Analyst, 1941) is also still in use. Dr Scott played the major role in the introduction

of direct reading emission spectrography into the Institute's armoury of analytical techniques and was responsible for the training of a great number of scientists in the disciplines of trace element analysis by emission spectrography and other ancillary techniques. He was valued as a colleague and as a highly-skilled scientist by all at the Institute and his wise and genial leadership will be sadly missed. We wish Dr and Mrs Scott a long and happy retirement.

Dr A. M. Ure, one of Dr Scott's life-long colleagues in the Institute, has succeeded him as Head of the Department of Spectrochemistry.

Mr J. Logan, of the Department of Mineral Soils, resigned from the service of the Institute under the voluntary premature retirement scheme on 31st March, 1981. He joined the Institute in 1948 as an assistant to one of our original members of staff, Dr H. G. M. Hardie, and upon the latter's retirement became responsible for the operation of the soil analysis unit in

Presentation to Dr R. O. Scott on 14 September, 1981. Mr J. C. Burridge, Mrs R. O. Scott, Dr M. L. Berrow, Dr R. O. Scott, Dr A. M. Ure and Dr T. S. West.

the Department of Pedology and for collation of the work of the unit with that of the Soil Survey teams who sampled the soil profiles all over Scotland. As a keen analyst Mr Logan also continually updated the analytical methods and latterly was closely associated with his Department's contribution to the Institute's Soil Data Bank project. His interest in staff welfare led to his serving as Chairman of the SARI Branch of the Institute of Professional Civil Servants for a period of several years. He was prominent in the social life of the Institute and is well known all over Scotland for the leading role he played in the production of the popular stage review "Scotland the What." His expertise and presence will be greatly missed in the Institute.

Dr R. Boggie, of the Department of Peat and Forest Soils, also resigned under the voluntary premature retirement scheme on 31st May, 1981, after 25 years' service. A graduate of the Botany Department of the University of Aberdeen, he joined the Institute staff in 1956 and obtained his PhD in the same year. After three years in the Department of Soil Survey, during which time he made significant contributions to a number of maps and reports, he joined the Peat Ecology Section and embarked with Mr A. H. Knight on a series of extremely well planned experiments on the use of radioisotopes, *e.g.* ^{32}P to study the distribution of plant root systems and of ^{3}H to follow the lateral and vertical movement of water, particularly in peat. His work revealed that whilst both lodgepole pine and Sitka spruce showed increased growth with depth of water table, pine roots penetrate deeper the lower the water table, whereas spruce roots are scarcely affected. In addition, under conditions of impeded drainage the pine roots could tolerate lower oxygen levels than spruce. Dr Boggie leaves behind a legacy of techniques and field instrumentation that will long form the basis for future assessment and evaluation. He also leaves behind him an enduring reputation of fine experimentation and meticulous attention to detail. His warm and friendly personality made a lasting impression on all who knew him.

Visitors to the Institute

The Agricultural Research Council held their meeting at the Institute on 9th June, 1981, visited the laboratories on the afternoon of the 8th and met senior staff informally in the evening. The Director discussed the work of the Institute with Council members during their meeting. In the absence of the Chairman, the Earl of Selborne took the Chair at the Council meeting.

Short term visitors from overseas included: Mr A. K. Dergunov, USSR Secretary General of the International Peat Society; Dr B. Griepink, of the EEC Reference Bureau, Brussels; Dr R. Dudal, of the Land and Water Division of FAO, Rome; Mr Jin Qinhan, of the Chemistry Department of Jilin University, Chungchan, The People's Republic of China; Dr T. Prasad, of the National Dairy Research Institute, Karnal, India; Professor J. Burau, of the University of California (Davis), USA; Mr Meh Bin Awang, of the Department of Agricultural Engineering, University of Malaysia; Dr J. C. White and Dr S. E. Lindberg, of the Oak Ridge National Laboratory, Tennessee, USA; Professor F. Pellerin, of the Faculty of Pharmacy, University of Paris; Dr J. H. Johnson, of the Chemistry Department, University of Wellington, New Zealand; Professor T. Fujinaga, of the Chemistry Department, University of Kyoto, Japan; Dr R. L. Parfitt, of the DSIR Soil Bureau, Lower Hutt, New Zealand; Mr J. Crawford, of the Department of Conservation, Salisbury, Zimbabwe; Mr K. W. Nyamapfene, of the School of Agriculture, University of Zimbabwe; Dr B. Novak, of Prague; Mr J. Morris, CSIR, Pretoria, South Africa; Dr L. Pöppl, University of Budapest, Hungary; Mr T. Wild, of Shell Research, BV, Holland; Dr T. J. McClelland, of Colorado State University, USA; Mr Lu Shijan, of

the Agricultural Press, Beijing, The People's Republic of China; Dr M. S. Heaal, of the Soils and Water Research Institute, Giza, Egypt; Dr T. H. Brakke and Dr H. Hamodt, of Norway; Dr M. M. Iqbal, Agricultural Research Centre, Pakistan; Dr T. Wadsten, of the University of Stockholm, Sweden; Dr W. J. Goedert, of Embrada ICPAC, Brazil; Dr T. Eiland, State Laboratory for Soil and Crop Research, Copenhagen, Denmark; Mr S. P. Dhua, Mr S. N. Basu and Mr K. K. Das Gupta, of the Hindustan Fertilizer Corporation, Calcutta, India; Dr C. C. Choung, of Chenja National University, Korea; Dr H. A. Das, of The Netherlands; Dr K. Smienchalski, of Poland; Dr Paulo de Lima, SNLCS-Embrada Recife, Brazil; Dr R. Orwell, N.S. Wales Institute of Technology, Sydney, Australia; Dr M. Saeed, Ayab Agricultural Research Institute of Pakistan; Dr H. J. Bollinberg, University of Copenhagen, Denmark; Mr Li Fu-Di, of Huachung Agricultural College, Wuhan, The People's Republic of China; and Professor Shi Lianghe, Mr Lin Renrong, Mr Mei Xu, Mr He Yuoxi, of the Academy of Sciences, Beijing, The People's Republic of China.

Long term visitors from overseas included: Mr Garry Black, Memorial University of Newfoundland, Canada, working in the Remote Sensing Unit of the Department of Peat and Forest Soils; Dr Maria Vicente Hernandez, Centre of Applied Biology, Salamanca, Spain, working in the Department of Mineral Soils; Dr R. Lee, of the DSIR Soil Bureau, Lower Hutt, New Zealand, working in the Department of Soil Fertility; Dr J. M. Criado Luque, Department of Physical Chemistry, Seville, Spain, also working in the Department of Mineral Soils; Dr M. B. McBride, Department of Agronomy, Cornell University, Ithaca, New York, USA, working in the Department of Spectrochemistry; Miss M. M. Ron, Department of Soil Fertility, Universidad Nacional del Sur, Argentina, working in the Department of Plant Physiology; Mr C. J. Koch, of the Royal Veterinary and Agricultural University, Copenhagen, Denmark, working in the Department of Spectrochemistry; and Mr A. N. Pandey, of the Institute of Petroleum, Dehradeen, India, also working in the Department of Spectrochemistry.

Long term visitors from the UK include: Mr Alex W. Wilson, Senior Lecturer in Statistics at Robert Gordon's Institute of Technology, who spent six months secondment in the Institute's Department of Statistics; Dr A. Cowking, of the School of Physics of Robert Gordon's Institute of Technology, who spent two months in the Department of Mineral Soils; and Dr C. A. Shand, of the University of Aberdeen, who is spending two years on a grant from the Scottish Hospitals' Endowment Research Trust in the Department of Spectrochemistry working on trace element problems in relation to human nutrition. Short term UK visitors included: Dr D. H. Christopher, Director of Industrial Environmental Studies, and Mr H. A. Anderson, of the Huntingdon Research Centre; Dr B. Tinker and Dr Sanderson, of Rothamsted Experimental Station, and Dr R. J. Stevens and Dr and Mrs Adams, of the Department of Agriculture, Belfast; officials from ARC and DAFS, Ordnance Survey, NERC, SERC, NCC, Red Deer Commission, Strathclyde and Borders Regional Councils, Grampian Regional Council and the Highlands and Islands Development Board.

Group visits included delegates at the conferences held in Aberdeen by the European Society for Nuclear Methods in Agriculture and The British Society for Soil Science, a party of 20 visitors from the Association of Scottish Industrial Analysts and from the Remote Sensing and Strategic Planning Society, plus parties of students from the Universities of Aberdeen and Edinburgh, The North of Scotland College of Agriculture and various secondary schools.

Lectures were delivered by several of our overseas visitors including: Dr J. N. Johnson (N.Z.) on Mössbauer spectroscopy applied to the study of mineral structure; Dr R. L. Parfitt (N.Z.) on Imogolite and Allophane in N.Z. Soils; and Professor T. Fujinaga (Japan) on Trace metal characterisation in oceanography. Dr B. Ray, of the Department of Electrical Engineering at Robert Gordon's Institute of Technology, Aberdeen, spoke on Interfacing instruments with computers, and Mr M. S. Davidson, of the Institute's Department of Microbiology, spoke on the Chemostat and Coulter Counter techniques.

Honours and Appointments

Dr R. C. Mackenzie, Head of the Division of Pedology and the Department of Mineral Soils, received a plaque from the President of the Regione Emilia-Romagna at the opening ceremony of the 7th International Clay Conference in Bologna, Italy, as a recognition of cultural distinction. He was also elected to the Council of the Analytical Division of the Royal Society of Chemistry.

Mr E. Paterson, of the same department, received a competitive award from the Thermal Methods Group of the Royal Society of Chemistry, for an essay on the value of thermal analysis in the study of soil particle surfaces. The award consisting of a certificate and money prize was presented to Mr Paterson during the opening ceremony of the 2nd European Symposium for Thermal Analysis at Aberdeen University in September.

Mr B. F. L. Smith, of the Department of Mineral Soils, was awarded the degree of MSc of the University of Aberdeen for a thesis entitled "The use of organosilicon derivatives in a study on the weathering of soil parent materials."

Dr H. G. Miller, of the Department of Peat and Forest Soils, was awarded the International Union of Forest Research Organizations' Gold Medal in recognition of his outstanding research record. This was presented together with an illuminated scroll and honorarium during the opening ceremony of the 17th IUFRO World Congress in Kyoto, Japan. He was also awarded the DSc degree of the University of Aberdeen and appointed to serve on the NERC "Terrestrial Life Sciences Grants Committee."

Dr G. C. Stove has been appointed Assistant Secretary of the Remote Sensing Society and both he and Mr R. A. Robertson are members of the UK National Remote Sensing Centre's Working Group on Land Applications. Dr Stove is also a member of the Centre's Working Group on Data

Handling. Both working Groups advise the Technical Advisory Committee and Programmes Board of the Centre on matters concerned with future research and development.

Mr R. A. Robertson, Head of the Department of Peat and Forest Soils, gave an interview on peat developments in Caithness on Grampian TV in March, 1981, and another in Ireland for a peat documentary shown on BBC TV in August, 1981. Whilst in the USA in October, 1981, he also gave two TV interviews and two broadcasts on state (Minnesota) and local networks.

Mr J. S. Bibby, of the Department of Soil Survey, gave an interview on the Grampian TV programme "Country Focus" on the work of the Soil Survey Department and on the new 1:250,000 Survey activity which had just been completed at that stage.

Dr A. M. Ure has been appointed as an Associate Member of the IUPAC V.4 Commission on Spectrochemical and other Optical Procedures of Analysis.

Dr T. S. West, Director, was made an honorary member of the Japan Society for Analytical Chemistry and was awarded the Society's Medal and Scroll at the Society's 30th Anniversary Meeting in Kyoto, Japan, in October, 1981. He was appointed to the SERC's Working Party on Analytical Sciences and became Assistant Secretary General of the International Union of Pure and Applied Chemistry (IUPAC) at the 31st General Assembly in Leuven, Belgium. He represented IUPAC at the meeting of the Federation of European Chemical Societies' Working Party on Analytical Chemistry in Helsinki in August, 1981, and at the International Meeting of Chemical Society Presidents in Belgrade in September, and was one of the Royal Society's Delegates to the Council Meeting of IUPAC in August, 1981.

Visits Overseas by Staff, etc.

Details of visits overseas by staff and of UK meetings where lectures were given by staff are presented in Appendices 2 and 3 respectively.

Postgraduate Students

Two new research students have joined the Institute staff. Miss F. Proctor, who was awarded a DAFS Studentship, is working in the Department of Plant Physiology on calcium deficiency in selected plants. Mr M. F. Proe is working in the Department of Peat and Forest Soils on mathematical modelling of nitrogen nutrition of trees. Mr Proe was awarded a NERC/CASE Studentship to undertake this project. Both these students are studying for the degree of PhD of the University of Aberdeen. During the year two students, Mrs K. Welch and Mr D. Welch, were awarded the degree of PhD of the University of Aberdeen. Three students, Mr B. Thornton, Mr P. Wilson and Mr S. D. Young, have now finished their experimental work for the degree of PhD and are meantime writing up their theses for submission to the University.

Institute Events

The Council of Management met twice on 29th May and 27th November. The joint MISR/COSAC Consultative Committee on Soils also met in November.

During the year the Institute news magazine " Profile " will have reached its 61st issue by December. The Editor and Editorial Board of the magazine are to be congratulated on the continued success of their efforts and thanks are due to all who have written in its pages, particularly to some of our overseas guests who have written on various aspects of life and sometimes even soil research in their own countries.

Because of continuing shortage of funds no new building has been possible within the Institute during the year, but we have capitalised on available space underneath the foundations by creating a new room below the Department of Soil Fertility to provide sample storage and an area for housing deep freeze units for the storage of various specimens. Similarly, in the roof space one of the tank rooms, 405, has been benched to provide laboratory space for ^{15}N work and for instrumental development space for remote sensing scanners, etc. Transfer of crop drying ovens from the second-floor level laboratories of the Department of Soil Fertility to the crop-handling building has allowed a start to be made on conversion of this " high grade " accommodation area to additional much needed laboratory space.

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.

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.

B. D. Mitchell.

The work of the Department is aimed at obtaining information on the factors controlling the formation, composition, constitution and properties of mineral soils in Scotland. Such information is essential for a proper understanding of the complex soil system as it exists in the field and necessarily involves chemical and physical characterization of individual soil components, both inorganic and organic. Despite the fact that the properties of mineral soils are, by definition, determined mainly by the mineral matter present, the contribution of the organic matter to their development and present state can in no way be neglected.

The main technique used within the Department to characterize organic matter has, for the past number of years, been rapid pyrolysis followed by gas chromatography to separate and mass spectrometry to identify the entities produced. During the year a more elaborate data processing system has been obtained for the mass spectrometer: this enables direct mass spectrometric identification of the pyrolysis products and, by removing the gas chromatography stage, improves interpretation and obviates a possible source of error.

The specialized facilities and expertise available within the Department have been made use of, mainly in collaborative studies, by many outside bodies including DAFS, the Rowett Research Institute, the Universities of Aberdeen and Glasgow, the Transport and Road Research Laboratory and companies connected with the oil industry in Aberdeen.

Soil Analysis

Chemical Studies. Systematic chemical and physical examination of all profile samples collected by the Soil Survey of Scotland in the 1979 and 1980 field seasons has been completed. Profile samples have also been examined

for other departments of the Institute and for outside bodies — e.g. DAFS, in connection with the restoration of open-cast coal sites.

101, 104, 204, 207, 304, 801

Since the new computer was commissioned, work has progressed on establishing the Institute's Soil Data Bank, priority being given to the data for profiles from 1979 to date. 101, 703, 801

A study of the relationship between the degree of polymerization of silica, as revealed by the formation of organosilicon derivatives, and the degree of weathering of certain residual soils of north-east Scotland has been completed and a thesis on this subject[1] has been sustained by the University of Aberdeen for the degree of M.Sc. The silylation technique employed has enabled assessment of the stability towards acid conditions of commonly occurring minerals, poorly ordered inorganic material and crystalline clay minerals[2] and, in general, gives a measure of the weatherability rather than the degree of weathering of the parent material. 103, 104, 105

Losses and gains of major elements from and to horizons of three profiles from north-east Scotland have been determined and related to profile morphology and development[3]. Moreover, the variation in major and minor element contents of podzols and gley soils developed on glacial till derived from Old Red Sandstone (Devonian) sediments in the Orkney Islands (Sheets 118, 119, 120, 121 and apart 117) has been determined by X-ray fluorescence spectroscopy. 101, 801

Techniques are constantly being reviewed as a consequence of new developments. Assessment of a new method of sample preparation for X-ray fluorescence spectrometry has indicated that the accuracy previously attained for major and minor elements is maintained, whilst the analysis time is decreased. Furthermore sodium can be determined along with the other elements, thus improving the accuracy for this element over that obtained with the pressed-powder method previously used. For determination of total phosphate in soils, it has been found that a sodium carbonate fusion in platinum crucibles can be replaced by a sodium hydroxide fusion in nickel crucibles without sacrificing accuracy, but with a great saving in cost[4].

101, 104, 107, 801

The practical difficulties, referred to last year, in monitoring major elements in stream and soil water on catchment areas within the principal Soil Associations of north-east Scotland have been overcome and results for soil water are now available for a full year. This water is most acid (pH$\sim$4·1) in the Strichen Association and least acid (pH$\sim$6·7), as would be expected, in the Leslie Association; amounts of alkalis and alkaline earths are in the order Na>Ca>K>Mg except for the Leslie Association where, again not unexpectedly, magnesium predominates. The soil water also contains at least twice as much sodium as silicon and 5-30 times as much aluminium as iron. As regards anions, sulphate is most abundant in Insch, Tarves and Foudland soils, whereas chloride predominates in the Strichen, Countesswells and Strathfinella Associations: in the Leslie Association, bicarbonate is dominant. Nitrate is always present in the lowest concentration and phosphate has not yet been detected. 101, 105, 106, 107

Thermoanalytical Studies. Despite the increasing number of thermoanalytical techniques available over the years[5, 6] and improvements in technology[7], differential thermal analysis (DTA), differential scanning calorimetry (DSC) and thermogravimetry (TG) still tend to be the most widely used[8, 9, 10, 11]. Recent thermoanalytical studies on akaganéite (β-FeOOH) have shown that decomposition is accompanied by evolution of a red-brown vapour that condenses into large crystals of hematite: this chemical transport is believed to occur through chloro-iron complexes formed by the chloride ions present in the original akaganéite[12]. The fact that DSC can yield much information on the nature of particle surfaces has been established[13] and it has more recently been shown that, by choice of suitable experimental conditions, DTA can be used likewise[14]. That the value of these techniques is not restricted to inorganic materials is well exemplified by a DSC investigation of the effect of exchangeable cation on the decomposition of humic acid. Not only do pH value, time of saturation and basicity of cation affect the curve, but the results obtained enable an assessment to be made of the mechanism of the decomposition reaction[15].

101, 103, 104, 105, 107

Soil Mineralogy

In the classification of Scottish soils, one of the main criteria employed is the lithological nature of the parent material (usually a glacial till), as this has a profound influence not only on the morphology of the profile, but also on the inherent fertility of the soil. Thus, release of plant nutrients on weathering and their retention in available or unavailable form by the secondary products of weathering depend on mineralogy as well as on the relative importance of the weathering processes involved. One of the earliest stages of rock weathering is that attributable to lichens and lichen-encrusted rock is indeed a simpler medium than the soil for studying biotic/mineral relationships. It has already been shown that the weathering of basalt by *Pertusaria corallina* and of serpentinite by *Lecanora arta* is attributable primarily to the oxalic acid produced by these lichens[16, 17]. Investigations on further samples, with ancillary experimental studies, indicate that lichen weathering typically involves (a) solution and etching of grain surfaces by chelating acids, (b) preferential extraction of aluminium, iron and magnesium to leave siliceous residues, (c) precipitation of poorly ordered weathering products and (d) accumulation of relatively insoluble organic salts, mainly oxalates — events similar to those occurring in soils formed in cool temperate climates[18]. Scanning electron microscopy, which with electron probe microanalysis is essential in such studies[19], reveals that preferential dissolution occurs at specific sites (presumably those associated with structural dislocations) and etches out lamellar intergrowths that, because of their composition and structure, lead to lattice distortion at interfaces. These interpretations are supported by an earlier experimental study of the etching of feldspar[20]. 103, 104, 109, 508

The fact that biotites separated from Lower Old Red Sandstone sediments, although fairly highly oxidized, have lost little of their structural iron tends to refute the suggestion that they are responsible for the finely dispersed hematite that is the colouring agent[21]. 103, 104

Two expanding minerals detected in a weathering sequence on a basalt in Morvern, Argyllshire, have been identified as an interstratified montmorillonite-vermiculite-illite and as an intermediate between chlorite and saponite[22, 23].

A dust-fall in north-west England has been identified, by clay mineralogical methods, as having a Saharan origin[24]. Studies on the aluminium hydroxide mineral nordstrandite, in collaboration with Professor P. Violante, University of Naples, Italy, have shown that the morphology of the crystals depends on the conditions of formation[25]: these investigations are continuing. 103, 104, 109, 207

Clay Fraction. Because of its small particle size and consequent large surface area, the clay fraction has a very significant effect on soil properties, the nature of this effect depending on the properties and proportions of the various components present[26]. Because of the information that can be deduced from identification of these components the systematic study of the clay mineralogy of profile samples provided by Soil Survey has continued with the examination of samples derived from Old Red Sandstone rocks of the Orkney Islands (Sheets 118, 119, 120, 121, part 117). Some of these, and similar soils from a wide area of the Scottish mainland, have been found to contain a strontium-bearing phosphate mineral, goyazite: the significance and possible origin of this mineral are being further investigated. Information on the unusual swelling hematite/layer-silicate complex[27] described last year has been referred to the International Mineralogical Association for formal recognition of this material as " Macaulayite " a new mineral species. 103, 104, 105, 109, 207, 801

A sample of saponite from Orrock Quarry, Fife, examined by Dr A. Cowking, Robert Gordon's Institute of Technology, has been found to consist of two distinct aggregate shapes — fibrous and granular. X-ray diffraction and electronoptical examination have revealed that the fibres consist of bundles of orientated laths, whereas the particles in the granular material, being turbostratically arranged, show no preferred orientation. Although apparently of the same composition, the two types differ markedly in their ability to swell with glycerol. The reasons for these differences are being further investigated. A review of interlayer and intercalation complexes of clay mineral and their value in diagnostic studies has now appeared[28]. 101, 103, 109

A filamentous illite occurring in sandstones from the Magnus oilfield in the North Sea has been characterized. The appearance of this mineral within the rock pores is very susceptible to the drying method used: least distortion from its natural mode of occurrence appears to result from critical-point drying. Some discrepancies between X-ray and electronoptical data have yet to be resolved[29]. 103, 109

Collaborative studies with foreign organizations continue to yield useful data on the occurrence, stability and origin of clay minerals in soils. Thus, the study of Turkish soils[30], in collaboration with the Faculty of Agriculture, Cukurova University, Adana, Turkey, has been extended by a visit to the

area and collection of further samples. Examination of samples of wadi soils from areas where no palygorskite occurs in the surrounding rocks, supplied by the Faculty of Agriculture, University of Riyadh, Saudi Arabia, has confirmed the widespread occurrence of this mineral in soils of the Arabian peninsula and its *in situ* formation[31]. Studies on the nature and origin of clay minerals in Italian Andosols are also continuing in collaboration with the Instituto di Chimica Agraria, University of Naples: a joint paper on this subject was presented at the 7th International Clay Conference, Bologna and Pavia, Italy, September, 1981. 103, 104, 105, 107, 109

Surface Characteristics of Soils and Soil Components

The relationship between the surface charge characteristics of moist soil, as measured by potentiometric techniques, and the degree of dispersion of the clay fraction at various pH values is being investigated for some iron podzols of north-east Scotland. Initial results indicate that ultrasonic dispersion must be used with caution because prolonged treatment causes breakdown of the sand- and silt-sized fractions. 101, 103, 106, 801

Studies on the ochreous deposits that cause severe practical problems by blocking field drains have been extended by examination of the mineralogy and morphology of the iron oxide phases associated with specific macromorphological features in a ground water gley on alluvium. The drainage water in this profile contains 10-25 ppm Fe(II) which, on oxidative hydrolysis, yields a mixture of two poorly ordered iron oxyhydroxide minerals, but this mixture may well age to goethite, which is the principal iron oxide mineral in the ochreous layer of the profile.
101, 106, 107, 109, 801

The morphology of manganese oxides from small nodules that commonly occur in some Scottish gley soils suggests the presence of a lamellar mineral with a poorly ordered structure. Further studies on a synthetic model compound with a more ordered structure — the mineral buserite — which forms an interlayer complex with dodecylammonium ions[32], indicate that amines of chain lengths C_4 to C_{18} can also penetrate between the sheets. Although the basal spacings obtained are linearly related to chain length, the presence of some water molecules seems essential for an ordered complex. 103, 105, 106, 107, 109

The kinetics of water sorption on soil components have been studied using a sorption microbalance under a high vacuum[33]. 106, 107

Organic and Biological Materials

Pyrolysis-gas capillary chromatography has yielded data on the relative variations of polysaccharide-related and polypeptide-derived products that enable a humification sequence to be established for a group of podzol soils. The organic matter in podzol B_h horizons is transitional between that in podzol A and that in brown forest soil A horizons and is closer to that in the overlying A horizon than to that in the underlying B_s. Discrimination between horizons by this technique was good. 108, 801

In collaboration with the Departments of Soil Organic Chemistry and Soil Fertility, alkaline and water extracts of soils and peat have been examined by pyrolysis-gas capillary chromatography. For humic acids, lignin products and nitrogen compounds are enhanced relative to the original sample, whereas polysaccharide-related compounds are depleted: reverse relationships hold for fulvic acids. Low-molecular-weight water-extractable material shows mainly acetic acid and phenol, but polysaccharide-related products increase in amount with molecular weight and high-molecular-weight material resembles fulvic acid. Humins yield a more complex pattern, similar to that from whole soils[34]. The analytical potential of pyrolysis techniques for soil studies has been critically assessed[35].

108, 301, 304, 305, 604

Quantitative pyrolysis studies of proteins have indicated the source of pyrrole-ring compounds to be proline and hydroxyproline amino acids: tests are in progress to check whether similar compounds in soil pyrolysates have the same source. Other materials examined by pyrolysis methods have included deposits in drainage tiles, synthetic melanoidins, hydroxylated chain compounds and polyacrylamide — results from the last giving information on the extent of chain folding. 108

Improvements to equipment have included a direct interface between the gas chromatograph and the mass spectrometer that operates within the limitations of the present pumping system and capillary columns capable of separating complex alditol acetate mixtures. The new data processing system for the mass spectrometer is currently being commissioned and pyrolysis-mass spectrometry studies are being resumed. 107, 108

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2. PEAT AND FOREST SOILS

R. A. Robertson

The work of the Department is primarily concerned with the classification and evaluation of peat, vegetation, crop and other terrain resources and with studies designed to obtain a better understanding of the biogeochemical factors controlling plant production on highly-organic and related marginal soils.

During the year, further progress has been made in the development and application of remote sensing, photogrammetric and image processing techniques for terrain surveys, resource mapping and environmetal monitoring[1, 2]. In collaboration with the Department of Agriculture and Fisheries for Scotland and the Scottish Development Department (Air Photo Unit), information derived from airborne and satellite sensing systems is currently being employed in a survey designed to map and monitor the distribution and spread of bracken in Scotland. Close collaboration on the development and application of remote sensing techniques is being maintained with the Royal Aircraft Establishment, Farnborough, the Department of Industry (Space Division), the University of Aberdeen and Robert Gordon's Institute of Technology. Likewise, in association with the Forestry Commission (Research and Development Division), the Scottish Development Department, Tayside and Grampian Regional Councils and the Water Research Council, an investigation has been initiated to determine the possibility and effect of disposing sewage sludge and effluent on forest land. Joint studies with the Central Electricity Generating Board on the effect of atmospheric pollutants on plants, soils and natural waters have continued and the effects of afforestation on soil and water acidity are currently being investigated in collaboration with the Swedish University of Agricultural Sciences.

In relation to the practical and wider application of these and other developments, close liaison has been maintained with representatives from other organizations including the Highlands and Islands Development Board, the North of Scotland Hydro-Electric Board, the Peat Producers' Association, the Hill Farming Research Organization, the Scottish Agricultural Colleges, the Institute of Terrestrial Ecology, the Institute of Geological Sciences, the Scottish Institute of Agricultural Engineering, the Council for Applied Science in Scotland, Grampian and Highland Regional Councils, the Institute of Hydrology and other agencies in both the public and private sector.

Peat and Terrain Resource Surveys

Increasing awareness and re-assessment, at both national and international level, of the value of peatlands and peat for agriculture, forestry,

horticulture and, significantly, for conversion to energy and other products, have underlined the importance of the Department's data bank of scientific and technical information on Scottish peat resources and methods of development[3]. In collaboration with the Highlands and Islands Development Board, Highland Regional Council and the North of Scotland Hydro-Electric Board, key areas in Caithness and Lewis have been identified and evaluated with respect to the production of air-dry peat fuel for domestic and space-heating projects, and for the generation of electricity in specific local situations. These and possible future developments will necessitate careful planning and monitoring, especially with respect to drainage and drying conditions, peat quality and processing and site re-habilitation, areas in which the expertise available through the Institute, the North of Scotland College of Agriculture, DAFS and the Forestry Commission can play an important role. 112, 114

Further ground-truth surveys have been undertaken in Lewis and Shetland to verify the nature and distribution of peat and vegetation types. These studies will form the necessary basis for output of both small and large-scale maps using aerial photographs and space imagery. The first of a series of experimental maps, derived from LANDSAT imagery, showing the peat and terrain categories of Lewis and North Harris at 1:100,000 scale has been published in association with the Royal Aircraft Establishment, Farnborough[4]. An account of the peatlands around Fife and Kinross has been prepared for publication in the appropriate Memoir of the Soil Survey of Scotland. Palaeobotanical studies on a limited scale have continued on samples from sites in Fife and Orkney. 112, 114, 119, 801

At the request of the Department of Agriculture and Fisheries for Scotland, a major survey is in progress to map the present distribution of bracken in Scotland and, taking account of climate and soil type, to assess and monitor the nature and rate of colonization. In the first phase of this work, information derived from ground survey, multi-level aerial photography and satellite (LANDSAT) imagery over a large part of Central Scotland is being evaluated to determine the most appropriate scale to adopt for mapping bracken cover, 1 ha or more in area, on a national basis. Up-to-date aerial photography has also been acquired for other test areas, including Central Perthshire, and recent LANDSAT scenes, covering the whole of Central and South-West Scotland and the Grampian Region have been geometrically corrected to the O.S. National Grid and resampled at the Royal Aircraft Establishment, Farnborough, to 50-metre picture elements (0·25 ha). The computer tapes and precision-processed negatives will provide an excellent basis for future mapping. 112, 119

Multi-temporal LANDSAT Classification Project

The object of this joint research project with the Royal Aircraft Establishment, Farnborough, was to attempt to develop an automated land cover classification procedure for a test block of terrain much larger than either the existing Laurencekirk or Buchan Test Areas previously described. Five LANDSAT scenes, three from 1977 and two from 1979, with a good

seasonal range were selected for study. The first step was to collect ground truth data on land cover and crop records from sample farms for the relative scene dates. For the main interactive experiments, this information was sent to Farnborough where training areas were located on the image digital processor (IDP 3000) and histograms were produced of the reflectance values of selected land cover types; this procedure was completed at the Institute. A complete data set of spectral signatures of four land cover types (grass, cereals, forestry and moorland) for all training sites on each tape has now been produced. A marked seasonal trend is evident when the reflectance ranges are plotted seasonally for each spectral band. A complete set of statistics on band relationships and sun elevation is being processed and catalogued. Such relationships and others should prove invaluable in selecting an automated multi-temporal classification procedure for land cover types. 118, 119

The next stage is to rectify all tapes geometrically to the National Grid and to overlay each Grampian Test Block, once registered on the IDP 3000, for change detection. The full interactive capabilities of this processor will then be tested, based on the statistical analysis of the data sets, and will hopefully lead to an automated classification method. Although it has not yet been possible to rectify all five tapes, a digital mosaic of the entire Grampian Region, rectified to the National Grid, has already been produced. 118, 119

Airborne Thermal Survey of Aberdeen

On 11th December, 1980, Europe's first city-wide airborne thermographic survey was conducted over Aberdeen, covering an area of some 100 Km^2 of which 25 per cent was agricultural and afforested land. The survey was flown by Clyde Surveys Ltd. using a Daedalus DS-1230 line-scanner, and high resolution night-time thermal imagery was obtained from 24 runs over the city between 2000 and 2430 GMT, at a height of 600 metres. The Instantaneous Field of View (IFOV) of the scanner was 0·85 metres, yielding a cross-track swath of 800 metres with each run.

A ground temperature survey was conducted at time of aircraft overpass to provide an absolute calibration of the airborne data. Measurements of grass surface temperature were made at 15 minute intervals from 14 sites around the city. Automatic recording thermographs were installed at 4 sites and results from the ground truth survey show the urban " heat island " of Aberdeen, which was well formed at 2030 GMT but, due to changing meteorological conditions, had collapsed by 2200 GMT. At the request of BP Petdev and other members of the consortium involved in sponsoring the thermal survey, a unique micro-computer controlled system was assembled by Dr M. J. Adams (Spectrochemistry) to enable the analogue-to-digital conversion of the scan data. This allowed the user immediate access to the original temperature data, which could be manipulated and displayed on a high resolution colour graphics terminal or on a computer line printer[5]. 118, 119, 120

Of the 8 sample areas in the city, three have so far been digitised and studied in detail — the harbour area, the Bridge of Don area and Donmouth,

and the agricultural and wooded area centred on Craibstone and MacRobert Experimental Farm. To calculate energy loss, it is necessary to have values for radiant temperature, air temperature, windspeed and emissivity. By substituting these values in empirical equations for surface temperature, radiative, convectional and evaporative heat loss, it is possible to derive an estimate of total heat loss from individual buildings[6]. On the agricultural areas, the appearance and distribution of wind-induced 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[7]. It is evident that differences in temperature of field crops are related to management practices. It has also been demonstrated that the thermal imagery of Aberdeen can be used to detect and monitor circulation patterns and sources of pollution in the coastal zone. 118, 119, 120

SAR 580 Experiment

The main objective of this experiment is to evaluate the potential of Synthetic Aperture Radar (SAR, a microwave remote sensing technique) as an all-weather capability for natural resource surveys and agricultural research applications in Scotland. The Macaulay Experiment, (21GB), approved by the European Space Agency, comprised a 245 km transect, approximately 7 km wide, extending from a sea area N.E. of Rattray Head (north of Aberdeen) south along the coastline to the Moorfoot and Lammermuir Hills (S.E. of Edinburgh). G. C. Stove was appointed site co-ordinator for this Block (GB1), other investigators involved being from the Forestry Commission, the Universities of Aberdeen and Glasgow and University College, London. 118, 119

On 6th June, 1981, a Canadian Corvair 580 aircraft acquired X and C band dual polarisation SAR imagery of the experimental block. Ground data collected before, during and after this overpass involved three separate programmes of work related to agricultural applications[8], aerial photography and hydrographic survey. A report on the Ground Data Collection Programme has been submitted to ESA by the site co-ordinator. Once received, imagery in the form of high-quality photographic products and digitally sampled raster data on computer compatible tapes will be fully interpreted and correlated with ground data and the results used to assess the value of SAR imagery. 118, 119

Snow Monitoring

In collaboration with the Highlands and Islands Development Board, a study has been completed on the use of LANDSAT imagery in determining the extent of snow cover with particular respect to skifield developments. A one day experiment on the interactive classification of snow scenes was undertaken at Farnborough in January and aerial photography of selected sites in the Cairngorms and Northern Highlands was acquired in April. The initial success of this project has resulted in the submission of a proposal for a CASE studentship to undertake further research in this field in association with the Department of Geography, University of Aberdeen. 120

Developments in Automated Photogrammetry

The Macaulay Automated Photogrammetric Image Processing System (MAPIPS) is a hybrid system developed with a flexible suite of software options which allows data from ground, air and space to be digitised, manipulated and displayed interactively on a Tektronix 4027 colour graphics terminal. A Pet micro-computer controls map digitising and orientation and digitising of photogrammetric stereo-models, using the B8S stereoplotter and Ferranti-Cetec System 4 Digitiser. The original LANDSAT software developed on a Honeywell 66/80 mainframe has been re-written and extended in RATFOR, on the Institute's Data General Eclipse computer, and can be accessed via the Tetronix 4027. The main achievements have been in data capture, display, editing and processing, photogrammetric orientation of stereo-models, air survey, computations and the interaction and display of data from various source databanks (ground, air and space) for interpretation and geoscientific mapping applications.
119, 5703

Instrumentation

In collaboration with the Department of Spectrochemistry, further progress has been made in the construction of a low cost versatile multi-spectral scanner for use in light aircraft. A gyro-stabilised platform for this scanner has been built by Dr W. H. Ekin, of Robert Gordon's Institute of Technology. A monochromator for ground-based spectral studies, complimentary to those envisaged for the airborne scanner, is currently being tested. 118, 207

A new air-survey tracking facility has also been developed using a TV camera and small CRT display. This instrument is currently being used for aerial photographic surveys and will, in future, be employed with the multi-spectral airborne scanner. 118

Peat for Horticulture

Investigation of the physical properties of peat and peat products and the assessment of their characteristics as growth media using tomatoes as a test crop have continued along the lines previously reported. A study of the effect of water stress and form of nitrogen on the incidence of blossom-end rot in tomatoes grown in peat substrates has been completed[9]. In collaboration with a working group, established under the auspices of the International Peat Society, further progress has been made on the standardization of product declaration and methods of peat analysis.
114, 402, 5701, 5703

Nutrient Uptake from Forest Soils

Since 1973 field studies have centred on six experiments designed to elucidate the relationships between growth and element cycling in closed-canopy stands of Sitka spruce (*Picea sitchensis* (Bong.) Carr). With the completion this 5th year of data collection at the newest of the experiments, the planned phase of intensive field investigation is now ended. However, all the experiments are being refertilized to elucidate further aspects of

growth response. Meanwhile, laboratory facilities are fully stretched to cope with the samples of tree tissues, litterfall, humus and soil collected and stored during the intensive phase. Processing of the rapidly accumulating data is occupying an increasing proportion of the effort both of the Department of Peat and Forest Soils and the Department of Statistics.

115, 117, 5701, 5703

Results from the earlier study on nutrient movement in Corsican pine (*Pinus nigra* var. *maritima* (Ait.) Melv.) continue to present new opportunities for modelling and examining different aspects of nutrient uptake and cycling in coniferous forests. As described in previous reports, models have been developed to describe both the various fluxes of nutrients and their accumulation in the different parts of the ecosystem. Recently, the data on net primary production and nutrient accumulation has been brought together and published as yield tables detailing biomass and nutrient accumulation in different tree components by age and growth rate[10]. This information has been used in conjunction with measurements of release, both in litterfall and through-crown leaching, to estimate the annual nutrient demand by new growth and the rate of nutrient uptake from the soil[11]. Comparison of these results suggests that a considerable proportion of the demands by new tissues formed in any one year is met by retranslocation from older tissues, including foliage and branches prior to death. Thus, of a total annual demand of 138 kg nitrogen per ha for new growth in closed-canopy pine, only 69 kg comes from root uptake, the remaining 69 kg being supplied by retranslocation within the tree. Similarly, retranslocation provides 57 and 55 per cent, respectively, of annual requirements for phosphorus and potassium. Further calculations show that old foliage is the predominant source of most of the retranslocated nutrients, providing about 90 per cent of the amounts recovered within the trees[12]. 115, 117, 5703

These calculations are for large trees that no longer show a net increase in foliage biomass. When the position was examined for young trees, still actively expanding their crowns, it was found that as a consequence of the reduced ability to meet annual demands through internal recycling, coupled with a slower rate of cycling through litterfall and reduced capture of atmospheric nutrients, nutrient demands made on the soil reserves by trees aged 10 years was two to six times that made by 40-year-old trees[13]. This reduction in demand as trees close canopy means that there should then be a much decreased need for fertilizer application, at least until immobilization of nitrogen in the developing mor humus layer reduces the availability of this nutrient. The importance of these concepts, both to forest management and to the future development of forest nutrition research, has been the subject of a paper recently submitted for publication[14]. 115, 116, 117, 5703

Forest fertilization is now widely practised in many parts of the world[15]. The efficiency of this operation depends on accurate diagnosis and prescription of fertilizer application. Foliar analysis has generally proved to be a precise and robust technique, but the literature contains large and worrying differences in the levels of foliar nitrogen associated with optimum growth of conifers. Accordingly a series of experiments has been carried out on

Corsican pine in both forest and glasshouse to determine whether the optimum levels vary with either age or climate. Definitive tests on climatic effects are difficult but it appears not to be a factor. Age, however, is clearly important and it has been shown that during the years prior to canopy closure optimum foliar nitrogen concentration declines with the logarithm of mean tree weight, falling from 3·3 per cent in very young seedlings to a low value of 1·5 per cent in 2 m tall trees. After canopy closure the level increases to about 2·0 per cent[16]. It is clear, therefore, that for diagnostic purposes critical foliar nitrogen levels must be qualified by the age or developmental stage of the trees. 117, 5703

As in previous years, the department continues to provide a nutrition advisory service to forest nurseries based on soil analysis carried out in the Department of Soil Fertility. A recent notable feature has been an increasing need to prescribe lime for nurseries that have been in production for many years, even although the optimum pH for growth of coniferous seedlings is as low as 4·5 to 5·0. 117

Input of Nutrient and Pollutants from the Atmosphere

Experimental work is still centred on the study at Glen Tanar, aimed at measuring changes in the chemistry of rainwater as it passes through different vegetation strata, the humus and soil mineral layers and determining whether such changes differ between adjacent vegetation types. Early results suggested greater acidity in water collected beneath old pine than in that beneath young pine, spruce, larch, birch, or heather. However, it was not clear whether this represented greater filtering of acidic substances from the atmosphere by the old pine or whether the additional acidity was generated by the trees themselves. Accordingly, filter gauges of the type used in the earlier study[17] have been installed as close as possible to all the investigated stands. One dramatic result has been a marked neutralization of rainwater as it passes through the ground vegetation layer beneath the trees. The acidity is usually replaced, however, as the water passes through the humus layer, only to be largely neutralized at depth in the mineral soil. Even here, however, there is a suggestion that the water is more acid beneath pine, particularly old pine, than beneath the other vegetation types. 115, 116

In collaboration with scientists from England, Canada, Sweden, Norway, Japan, Germany, U.S.A. and The Netherlands, a review of the effects of SO_2 and its derivatives on plants, soils, streams and fish has been prepared for the International Electrical Research Establishment. A critical and wide ranging review of the literature suggests that " acid rain " is unlikely to damage natural vegetation nor harm any but the most sensitive soils. However, there seems little doubt that it can acidify streams and lakes in areas of thin soils and resistant geology where residence time of water in the soil may be short and weathering reactions slow[18]. 115

In collaboration with Dr S. I. Nilsson, of the Swedish University of Agricultural Sciences, a conceptual study of forest growth as a possible

cause of soil and water acidification has been prepared for publication[19]. Using data from the models of nutrient uptake and cycling in Corsican pine referred to above, it was concluded that trees in fully-stocked, even-aged forest can be responsible, as a consequence of excess cation uptake, for appreciable soil acidification early in the rotation. However, because the movement of these hydrogen ions is not accompanied by a mobile anion, acidification of drainage water seems unlikely. Acidity in rain, by contrast, is accompanied by a mobile anion and the input is markedly episodic; hence acid rain is likely to lead to increased acidity in streams. 115

Nitrogen Mineralization in Peat and Mor Humus

Relationships between the nitrogen, phosphorus and potassium contents of peats and peatland types, characterised by topography and vegetation, have been well established in earlier studies. The hypothesis that the availability of nitrogen in peat is related to nutrient content, and therefore to site characteristics, is now being tested over a wide range of peatland types. Rates of nitrogen mineralization, measured by incubation at 30°C under waterlogged conditions, chemical composition and acidity are being determined on samples from sites varying in peat depth, topography, vegetation and geology. 111, 116

A study of the nitrogen content of various particle size fractions separated from peat and the rate of mineralization during incubation has been completed[20]. The results show that the largest amounts of mineral nitrogen were produced in the fine fraction (0·005-0·05 mm), which contained 25-47 per cent of the total nitrogen, suggesting that, in peat, this material is a major source of plant-available nitrogen. 116

In collaboration with the Department of Microbiology, samples of peat have been taken from the controlled water-table experiment at Lon Mor, Inverness-shire. Levels of inorganic and mineralizable nitrogen in fresh and incubated peat, respectively, have been compared with numbers and types of bacteria. Statistical analysis of the results is now in progress. A joint study is also in progress to investigate the relationship between microbial biomass and mineralizable nitrogen in different types of peat and forest humus. 116, 503, 513, 5703

Investigations into the decomposition and turnover of ^{14}C labelled microbial material in peats are being conducted jointly with the Departments of Soil Organic Chemistry and Microbiology. 116, 305, 512

Mineralization and leaching of plant nutrients from decomposing litter and humus are being studied under field conditions at Glen Tanar, near Aboyne. Extracts (1M KCl and 0·01M $CaCl_2$) and leachates of samples taken on a monthly basis are being analysed to determine the chemical forms of nitrogen, phosphorus and sulphur as well as the amounts of calcium, magnesium and potassium. 115, 116

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3. SPECTROCHEMISTRY

A. M. Ure

A. M. Ure

R. O. Scott

The general direction of the Department's work this year has followed the pattern of previous years. The principal areas of study continue to be the investigation of the distribution of trace elements in soils, soil profiles and plant materials, the examination of the structure, composition and forms of soil constituents, the provision of a trace element analytical service to other departments, and the North of Scotland College of Agriculture, and the development of analytical methods appropriate to those areas of research. This year has seen the departure of Dr R. O. Scott into retirement after some 13 fruitful years as the Head of the Department. A valedictory tribute to him and to his work is given in the Introduction.

In addition to attendance at, and the presentation of lectures to, various national and international conferences detailed elsewhere in this report, members of staff have been represented on a number of national and international committees and working parties. These include IUPAC Commission V-4 on Spectrochemical Methods (R. O. Scott), DAFS Consultative Committee on Spectrochemical Work (T. S. West, Chairman, R. O. Scott, Tech. Secy., and A. M. Ure), DOE/WRC, Standing Committee of Analysts (Main Committee, A. M. Ure; Working Group 4·0, M. L. Berrow), Annual Reports on Analytical Atomic Spectroscopy, Editorial Board (B. L. Sharp, J. C. Burridge and A. M. Ure), and the Association of Scottish Industrial Analysts (J. C. Burridge).

Trace Elements in Soils, Plants and Biological Materials

A considerable portion of the department's analytical effort continues to be devoted to the determination of elements likely to be introduced to soils and plants from sewage sludge, distillery wastes and industrial and other effluents. This work has involved not only the development of suitable preparative and analytical methods, but also continuation of the analysis of

samples from the ADAS long-term sewage sludge experiments and from studies conducted by this Department and by the Department of Soil Fertility. The Department is taking part in the certification analysis of a number of soils and sludges, in collaboration with the Community Bureau of Reference of the E.E.C., who intend to make some of these available as Standard Reference Materials. 201, 202

The development of Spark Source Mass Spectrometry for the analysis of biological materials has been furthered by the appointment of Dr C. A. Shand to a 2-year Research Fellowship devoted to the development of multi-element methods for human and animal materials and reinforcing concurrent work in the department on samples of animal origin. 205

A comprehensive account of the properties and concentrations of the elemental chemical constituents of soils has been presented in a review of the literature based on over 1000 references[1]. This has been accepted for publication and incorporates tables containing the mean, and ranges of, soil contents for 68 elements compiled from the relevant literature. A discussion of the role of soil as the source of trace elements, presented to the Royal Society by the Director[2], has been published. 201

Soils and Soil Parent Materials. The determination of trace elements in selected soil profiles sampled by the Department of Soil Survey has continued this year with work on soils from the areas covered by Sheet 85 (Rothes), Sheets 117 to 122 (Orkney) and Sheet 75 (Tomintoul). 101, 201

The study, reported last year, 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 been accepted for publication[3]. 101, 201, 703

Trace element data were provided for samples from the soil profile pits visited on field excursions of the Autumn Meeting of British Society of Soil Science held at Aberdeen University in September. The total contents of 15 and the extractable contents of 11 trace elements were reported in Appendix 1 of the Programme and Guide to Excursions produced for the meeting. 101, 201

Analyses of 31 topsoils from various parts of Scotland for total selenium content ranged from 0·40 to 1·59, mean 0·87 mg/kg. The soils with the lowest selenium contents were those of the Corby (0·53) and Dreghorn (0·40) Associations, which are both developed on parent materials of sand and gravel. Four soil profiles of the Auchenblae, Countesswells, Insch, and Thurso Associations respectively, comprising 25 samples, were also analysed. Total selenium contents ranged from 0·11 to 1·15, mean 0·47 mg/kg, and tended to be greater in the upper horizons of the profile. There was a suggestion of some small increase in content in the B horizons of the profiles, possibly associated with the presence of iron. These data have relevance to the occurrence of selenium deficiency disease — "White muscle disease" — in grazing livestock. 201, 206

The very high EDTA-extractable iron levels in the B_h horizons of iron humus podzols and iron podzols and the high acetic-acid extractable

aluminium in the B_s horizons of podzols have been interpreted in a re-assessment of podzol formation. A report of this work has been accepted for publication[4]. 201, 207, 208

As a contribution to the COSAC/SARI — Trace Element Study Group, the total contents of 8 trace elements in the B horizons of some 600 soil profiles, comprised of some 1200 samples, have been summarized. This data will serve as a preliminary indication, to agricultural advisors, of the soil associations on which cobalt and copper deficiencies and molybdenum excesses are most likely to arise. The B-horizon samples were chosen because, unlike the S or A-horizons, their trace element contents are largely unaffected by surface additions of lime, fertilizers, manures, pesticides, waste materials and by trace element treatments. The use of B-horizons has the further advantage that both cultivated and uncultivated profiles can be assessed and compared. 201

Soil associations where the B-horizon samples consistently contained <5 mg/kg total cobalt, and there is therefore a high risk of cobalt deficiency affecting animals, were Ardvanie, Corby, Countesswells, Cromarty, Dalbeattie, Eckford, Fraserburgh and Kindeace. Soil associations where the B-horizon samples consistently contained <5 mg/kg total copper and where there is therefore a high risk of copper deficiency were Ardvanie, Cadboll, Corby, Countesswells, Fraserburgh and Kindeace. Soil associations which appear in areas covered by several different soil survey sheets and where the B-horizon samples contained 3 mg/kg or more of total molybdenum, with a consequent risk of molybdenum excess affecting animals, included Darleith, Dreghorn, Ettrick, Rowanhill, Sourhope, Strichen, Tarves, Thurso and Yarrow. Soils containing <5 mg/kg total cobalt or copper, or >3 mg/kg total molybdenum were also found in many other associations where the risk of deficiency or toxicity problems may range from high to very low. 101, 201

Soil Status and Plant Uptake. In collaboration with the Department of Soil Organic Chemistry, laboratory and pot experiments have been continued 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 the long term disposal of distillery waste. The copper contents of ryegrass and lucerne grown in pots showed little difference at the first sampling following incorporation of increasing amounts of peat at three levels of addition; lucerne contents as high as 50 mg Cu per kg DM were found. After liming, however, to raise the pH of all pot-soils to around 5·5, the copper contents were reduced from 11·4 to 8·9 and from 43 to 23 mg per kg DM in lucerne. A paper on the nature and origin of the organic matter-metal complexes of soil has been published[5]. 201, 307

The analysis of soils and plants from two long-term sewage sludge experiments at ADAS Experimental Horticultural Stations has continued. Nearly ten years after the sludges, highly contaminated with Zn, Ni, Cu and Cr, were added, these elements persisted in the soils in readily extractable

forms. The considerably enhanced uptakes of Zn and Ni by grasses and clover correspond to the amounts extractable from the soils. While enhanced Cu levels were also obtained these did not correlate with extractable soil contents. No evidence of increased Cr contents has been found. The persistent effects of sludges applied annually during 1968 to 1971 at Luddington were similar to those from an equivalent total amount applied in 1968 as a single application. A further report of this work has been published[6].

Soil samples taken early this year, thirteen years after sludge application, have been analysed for acetic-acid extractable trace element contents. Levels of Zn, Cu, Ni, Cr, Cd and Co in the treated soils have fallen slightly between the years 1972, 1976 and 1981, but high levels, particularly of Zn and Cu, still persist. 201, 202

The use of 2-ketogluconic acid, a naturally occurring acid produced by soil bacteria in the rhizosphere, as a soil extractant for trace elements, has been assessed. This chelate shows promise as a diagnostic extractant for a number of trace elements in soils and, under natural conditions, its basic production may promote the availability to plants of such biologically important elements as Co, Cu and Zn. A paper reporting this work has been submitted for publication[7]. 201, 202, 502

A chapter for a book entitled, "Metalle in der Umwelt," edited by E. Merian has been prepared by M. L. Berrow and J. C. Burridge, and discusses uptake of metals, their distribution in and effects on plants. This will be published by Verlag Chemie, in German[8]. 201, 202

The Department has collaborated with the Department of Soil Fertility in the analysis of plants from their cobalt and copper field experiments and assisted the Forestry Commission, through the Department of Peat and Forest Soils, in their experiments on copper deficiency in conifers. Samples of feedstuffs have been analysed for the Rowett Institute to help identify suitable materials for low-cobalt diet experiments. 117, 202

The number of samples analysed this year by d.c. arc emission spectrometric methods has shown a significant increase, but staff limitations have still prevented a return to the higher sample through-put of earlier years, and samples from a number of completed field experiments have not yet been analysed.

Miscellaneous materials analysed during the year include samples of litter, liver and kidney from Dr McMurray, Northern Ireland; soils and extracts of wood from the Forestry Commission; soils from the Miln Marsters Group Limited, Norfolk; fungus from the National Vegetable Research Station; fish meal from Unilever, Aberdeen, and chemical concentrate samples from Prof. Velasco, Phillipines. A standard, Rye Flour, issued by I.A.E.A., Vienna, for collaborative analysis and a standard low-alloy steel made by the Association of Scottish Industrial Analysts have also been analysed. 5205, 5206

Spectrochemical Methods of Analysis

Current techniques and future developments in the spectrochemical analysis of trace elements have been reviewed[9] and the application of atomic absorption and flame emission methods to soil analysis discussed[10]. Analytical techniques for metal and metalloid analysis in soils have also been surveyed and assessed[11]. 205, 206

Arc-Emission

Arc-emission methods for the determination of trace elements continue unchanged from last year. The high current, up to 25 A, gas-sheathed arc source has been used to investigate the possibility of determining, by spectrographic analysis, the elements cobalt, molybdenum and zinc directly in plant ash, without recourse to a pre-concentration technique. The limits of practical determination in plant ash were Co, 3 mg/kg; Mo, 1 mg/kg and Zn, about 100 mg/kg. It was concluded that, since cobalt could not be determined at the animal deficiency level (circa. 0·5-ʌmg/kg in ash), direct analysis of ash could not yet replace the pre-concentration method. 205

Aqua regia digestion of four sewage sludge treated soils has been compared, in replicate, with bomb digestion using atomic absorption spectrometric analysis. The results show that aqua regia digestion extracts over 80 per cent and, in some cases over 90 per cent, of the total contents of Cd, Cu, Mn, Ni, Pb and Zn (overall mean 86 per cent). Examination of these soils and also some soils contaminated with distillery waste have shown, however, that some 10 per cent of the total copper in the soil is retained in the acid-insoluble residue remaining after aqua regia digestion, filtration and washing. 201, 206

Emission and Atomic Absorption Spectrometry. The number of routine determinations of major cations and of Cu, Zn and Mn decreased significantly over the year while that of Al, Cd, Ni and Pb considerably increased. The reductions reflect, in part, the continuing problems of rapid junior-staff turnover and also the inevitable difficulties in the introduction of new instrumentation. They also stem from an increase in the number of different sample types presented for analysis and, as indicated by the increased number of Al, Cd, Ni and Pb analyses, an increased involvement in problems associated with sewage sludge experiments. Despite these changes the number of elemental analyses performed over the year totalled some 88,000 compared with 90,000 in the previous year. 5206

The work of interfacing the three-channel atomic absorption/emission spectrometer, described last year, to an Apple II, micro-computer system is almost completed. This has the object of providing automatic computation and print-out for the rapid routine analysis of Ca and Mg in soil extracts. A description of the technique developed for the determination of ten major and minor elements in small (50-100mg) soil and mineral samples (Ann. Report No. 48, 1977/78), using a lithium metaborate fusion/nitric acid dissolution procedure, has now been accepted for publication[12]. This

method makes use of the I.L. 751 atomic absorption/emission spectrometer with nitrous oxide/acetylene and air/acytelene flames. This instrument, because of its high sensitivity and precision, has found wide application in various specialized analyses. For the determination of aluminium in various waters the range of concentrations is so large (0·01 to 200 mg/kg) that it is necessary to use both the nitrous oxide/acetylene flame and the I.L. 555 graphite furnace atomizer. In addition to the major elements, Ca, Na, K and Mg, other elements determined in a variety of samples by flame methods include Al, Au, Ba, Cd, Cu, Fe, Mn, Ni, Se, Si, Sr, Ti, V and Zn. 202, 203, 207, 5206

Considerable progress has been made in the elimination of major matrix interference effects in the determination of trace elements using the atom-trapping technique. The determination of Pb and Cd in waters, acetic acid and EDTA soil extracts at μg/l concentrations is now possible directly by the methods of atom trapping developed by Mr Lau Chau Ming working in the Department. An account of earlier work by Dr Khalighie on atom-trapping phenomena has been published[13] and a discussion on the use of metallic trapping tubes will be published shortly[14]. 206

Microwave Plasma Emission. The possibility of setting up an optical emission method for determining $^{13}C:^{12}C$ isotope ratios has been examined. A simple cryogenic sample preparation, similar to that used for ^{15}N, but releasing CO_2 from carbonate solution by the addition of acid, has proved very satisfactory. Under the conditions suitable for operating a stable discharge in CO_2 on its own, the CO^+ 1st Negative System, used by other workers, is too weak to be useful. The use of the CO 3rd and 4th Positive Systems is being investigated. 205

Shifts of the $^{15}N^{14}N$ bandheads relative to the $^{14}N_2$ bandheads have been measured using spectra previously recorded on spectrographic plates and as pen-recordings during the development of the method described previously (Annual Reports 49 and 50) for $^{15}N:^{14}N$ isotope ratios. These isotope shifts have been found to be in good agreement with calculated values but differ slightly from the only other available published values. Reliable values are needed for the development of a micro-processor controlled, stepper-motor driven, scanning spectrometer which is being planned to increase the rapidity of isotope-ratio determinations. 205

Radiofrequency Plasma Emission. The configuration of the plasma torch has been finalised and acceptable performance obtained at a total argon consumption of 10 litres/min. A rigid, glass, cross-flow nebulizer, using a sapphire jewel for the gas delivery jet and a quartz, sample-uptake tube, diamond-lapped to a high precision, has been constructed for routine analytical work. The needle-valve, rotameter, gas-flow controllers for the plasma have been replaced by mass-flow controllers, operating at constant temperatures. Filters have been included in the gas supply lines to exclude gas-borne particulates. A high resolution (0·36 nm/mm linear dispersion) scanning monochromator and 16 bit mini-computer have been purchased and these are being integrated with the source unit to provide an instrument

for routine analysis. A review and discussion of the applications of radio frequency inductively coupled plasma (I.C.P.) emission spectrometry to agricultural materials has been accepted for publication[15].

Laser Spectroscopy. The laser remote sensing system, constructed from equipment supplied by the Royal Society, the Science Research Council and the Agricultural Research Council, has now been completed and is being used for atmospheric, sulphur dioxide studies from a fixed base within the Institute. Initial results suggest that the system has an effective sampling range of between 1·5 and 2·0 km.

A contract has been applied for, jointly with the National Physical Laboratory, under the European Communities Third Environmental Research Programme, to study gaseous denitrification on the field scale using infrared-laser, long-path, absorption spectrometry. If approved the project will run for three years commencing summer 1982.

Spark Source Mass Spectrometry. The development of methods for the analysis of biological materials has continued. Six series of synthetic powder standards based on a simulated liver ash matrix have been prepared. Each series contains some ten elements so that about sixty elements are included. All six series have been analysed in order to calculate Relative Sensitivity Coefficients (RSCs) for these sixty elements. To date RSCs have been calculated for about 40 of them. For completeness and comparison, an equivalent set of synthetic soil standard samples is being prepared and analysed. Results for some elements in both sets of standards were presented at the Symposium on Inorganic Mass Spectrometry, arranged by Prof. F. Adams (Antwerp University), and Dr A. M. Ure at the Euro-analysis IV conference, in Helsinki.

A second-hand AE1 MS7 spark source mass spectrometer has now been installed and is in process of restoration to full operation. One of the oil-diffusion vacuum pumps is currently being replaced by a turbo-molecular pump to assess whether independence, or partial independence, of liquid-nitrogen cooling can be achieved by using this type of pump. It is intended to adapt this instrument for more rapid multi-element analysis using electrical detection in place of photographic-plate recording. 205

A microprocessor-controlled system has been designed and constructed to provide measurement of preselected line density and mass number, in digital form on punched paper tape, for main-frame computer processing. The existing capability of recording a complete spectrogram on a pen-recorder is retained but much more rapid measurement should be obtained and a great deal of tedious measurement and computation avoided. The equipment is now being fitted to the existing scanning microdensitometer for evaluation. 205

A wide variety of sample types has been analysed over the year and these include rocks, soils, algae, fungi, sheep faeces and liver. The results of the analysis of some 50 samples derived from different soil fractions of 5 different soil types are now complete and will be assessed, in terms of the distribution of trace elements and the soil mineralogy, in collaboration with

the Department of Mineral Soils. A description of the application of Spark Source Mass Spectrometry to the analysis of soils, geological materials and natural waters awaits publication[16] and the technique itself has been reviewed[17].

Dr C. A. Shand has taken up a 2-year Research Fellowship, financed by the Scottish Hospital Endowments Research Trust and supervised jointly by Dr P. J. A. Aggett (Centre for Study of Metabolism of Trace Elements, Dept. of Physiology, University of Aberdeen) and Dr A. M. Ure. This research is devoted to the development of multi-element methods for human and animal materials using spark source mass spectrometric, neutron activation and spectrochemical methods of analysis. Initial work has been mainly concerned with the preparation, drying and ashing of bovine and sheep liver samples. Freeze drying equipment has been installed and milling equipment is being modified to replace the stainless-steel bushes and cutting blades with titanium components in order to minimize contamination of samples by biologically important elements such as chromium. Ashing techniques at 450°C, making use of alumina as an ashing aid for materials such as liver, are also being evaluated. It has been found necessary, for such samples, to make use of ytterbium as a second internal standard element to alleviate the interference problems caused by superposition of molecular ions on the indium internal standard lines used hitherto. 205

Development of the preconcentration method using cementation on aluminium (Ann. Report 50, 1979/80) is continuing and the degree of PhD has been awarded by Aberdeen University to Mrs K. Welch who carried out this research in the Department. Dr Welch has now left Aberdeen to take up a teaching post in Sunderland.

The application of this preconcentration method to the determination of gold and the noble metals has been discussed at lectures given to the Analytical Division of the Royal Society of Chemistry in Edinburgh and at the annual meeting of the Association Francophone de Spectrometrie de Masse des Solides held in Antwerp. In an extension of this cementation principle, the possible use of aluminium metal to remove copper from copper-rich effluents, such as pot ale and pig slurry, before disposal to agricultural land, has been discussed[18].

Molecular Fluorescence Spectrometry. An oxidative acid-digestion procedure, for the preparation of soil and plant samples, prior to the fluorometric determination of selenium, which does not involve the use of perchloric acid, is being investigated. Preliminary evaluation indicates that for plant materials the method gives results comparable to those obtained with the oxygen flask combustion procedure. Use of this new method has provided confirmation that in the oxygen flask combustion procedure losses occur for soil, however, by retention in the ash. The results for a number of soils analysed using this digestion method are discussed elsewhere in this report and an average selenium content of 0·69 mg/kg for 56 soils has been found, in good agreement with average soil selenium contents found in New Zealand soils (Wells, 1967).

Molecular Spectrometry of Soil Constituents

A translation of the standard advanced French text on the constituents and properties of soil has been undertaken, with a view to promoting the cross-fertilization of the French and Anglo-American soil research traditions[19]. The various physical methods that can be used for obtaining information on the chemical composition of soils and plants have been reviewed[20].

Optical Absorption Spectrometry. The conventional view of podzol-formation processes assumes that aluminium and iron migrate as fulvate complexes from A horizons to B horizons. This theory cannot, however, account for the fact that aluminium and iron are deposited largely in inorganic forms in the lower B horizon of Iron Podzols and Iron Humus Podzols. Strong evidence has now been presented[21, 22], which shows that, to account for the presence of imogolite and imogolite-like allophanes in podzol B_s horizons, aluminium must migrate as a hydroxyaluminium silicate sol. Formation of humus-rich B_h horizons are then explained by the precipitation of colloidal organic matter, which has passed through the A_2 horizon, on to the electropositive allophanes previously deposited in the B horizon. This mechanism accounts for the distribution, within the B horizon, of humic and fulvic acids, and of organic and inorganic forms of translocated aluminium and iron[4]. The remarkable parallelism that exists between the distributions of translocated aluminium and iron in podzol B_s horizons can be explained by the migration of mixed Al-Fe-Si hydroxide sols, which are almost as colloidally stable as pure Al-Si hydroxide sols up to an atomic ratio of Al:Fe of 1:1[23]. Pure Fe-Si hydroxide sols are much less colloidally stable than Al-Si sols, hence a well-developed B_s horizon in podzols may be linked to an adequate supply of weatherable Al.

201, 207, 304, 801

A study of the levels of silica in solution necessary to form the mobile hydroxyaluminium silicate sol has shown that the silicate complex is more stable than gibbsite when orthosilicic acid in solution exceeds 6 mg/kg SiO_2, a level generally exceeded in soil solutions. This work has also established that the complex has a well defined composition with an Al:Si ratio of two, identical to that of imogolite. This supports the view that the orthosilicate complex can be considered as a poorly ordered imogolite, and justifies the name proto-imogolite, previously suggested.

An investigation of the nature of the iron phase in podzol B_2 horizons has been undertaken in collaboration with the Department of Mineral Soils, and preliminary results from infrared spectroscopy and electron microscopy have indicated the presence of feroxyhite. As this form of iron hydroxide has been shown by Russian workers to be produced by rapid oxidation of Fe(II), its presence suggests that a similar mechanism may operate in podzol B_2 horizons.

109, 207

An electromagnetic method of separating and concentrating iron oxides has proved an essential tool in the study of the very small amounts of these oxides present in the clays from podzol B horizons. The same method has

also been effective in further purification and concentration of the hematite-silicate mineral, whose occurrence and structure, reported in the 50th Annual Report, has now been published[24]. New IR, X-ray, and thermogravimetric data for the purer mineral have now been submitted to the International Mineralogical Association, who will consider its eligibility as a new mineral species — Macaulayite. 104, 207

Several other collaborative studies with the Department of Mineral Soils are in progress. The importance of precipitated hydrous iron oxides, such as ferrihydrite and feroxyhite, in ochreous drainage-water deposits and the B horizons of podzols and brown forest soils, has stimulated further study of the structure and composition of synthetic forms of these minerals. Preliminary results suggest that ferrihydrite may contain sufficient structural hydroxyl groups to allow it to be formulated as an oxyhydroxide, FeOOH. This is a surprising result for a phase which earlier investigators had concluded contained no OH groups. Equally unexpected is the observation that much of this hydroxyl appears to be readily exchanged by a range of anions. 105, 207

Two papers on the swelling minerals developed during the weathering of a Scottish basalt have now appeared[25, 26]. One of these minerals, a swelling chlorite, is being investigated further to characterize its interlayer region. 104, 207

Collaborative studies with the Department of Soil Organic Chemistry into the structure of soil polysaccharides are continuing, using infrared spectroscopy to check the effectiveness of methylation and hydrolysis procedures. 208, 305

The Institute participated with several Aberdeen-based companies and local authority groups in a thermographic survey of Aberdeen City, the first to be undertaken in Europe. To digitise, analyse and display the airborne-recorded data, a microcomputer-controlled system was developed with the Remote Sensing Unit of the Department of Peat and Forest Soils, *q.v.;* the details will be published[27]. Construction of an airborne line-scanner for agricultural research is continuing jointly with the Robert Gordon's Institute of Technology. Studies are also being undertaken in the development of a portable spectrometer system for the recording of uv/visible region reflectance spectra. It is anticipated that the use of this instrument will provide ground-truth data for the interpretation of satellite-recorded images 112, 207

Mössbauer Spectroscopy. A course of lectures on Mössbauer Spectroscopy presented by Dr Goodman at a NATO Advanced Studies Institute (Ann. Rept. No. 50, 1979/80) has now been published[28]. A lecture presented at the Association Internationale pour l'Etude des Argiles (AIPEA) 7th International Clay Conference has also been published as a chapter in another book on advanced methods in the study of clay minerals[29]. A similar account was delivered to the Department de Chemie Minérale et Analytique of the University of Geneva. The use of Mössbauer spectro-

scopy in soil-plant studies was further discussed in a lecture at the 1st A.R.C. Agricultural Science Seminar on soil-plant relationships which has now been published[30].

As in previous years the main emphasis of the work on Mössbauer spectroscopy has been on the study of soils and clay minerals, and a paper on the spectra of aluminous goethites has been published[31]. EDTA-extracts (at pH 5·8) of some podzol B_h horizons have been investigated at a range of temperatures. Poor signal-to-noise ratios were obtained at ambient temperatures and at 77 K, but at 4·2 K a mixture of components was observed, one being magnetically-ordered. Subsequent work on Fe(III)-EDTA complexes has shown the existence of two forms, the relative concentrations depending on the pH at which they were formed. At 4·2 K they have been shown to correspond to the two components in the soil EDTA extracts. Thus magnetic ordering can be observed, in spectra from Fe(III) complexes with polycarboxylic ligands, at typical soil pH values and hence the presence of such a component in the Mössbauer spectrum of a soil does not necessarily imply, as has generally been assumed, the presence of a secondary oxide or oxyhydroxide. Work initiated in 1980 in collaboration with the University of Reading (Ann. Rept. No. 50, 1979/80) on the variation with depth of the iron components of some mottled clays, has now been completed. The collaborative work with the University of Illinois (Ann. Rept. No. 50, 1979/80) on a comparison of the ferrous/ferric ratios obtained by Mössbauer and chemical methods from a number of standard mineralogical samples has been completed and the results were presented at the AIPEA 7th International Clay Conference. It was shown that, although good agreement could be obtained between the two methods, very careful work was necessary. 203, 207

The study of montmorillonites and hectorites with Fe(II) and Fe(III) in the exchange sites, reported last year, has been continued with the aim of further characterizing the inter-layer species. In collaboration with Rothamsted Experimental Station, the Mössbauer spectra have been obtained for some glauconites, in which the iron was predominantly in the ferric form. Parameters for both ferrous and ferric components were similar to those previously reported by other workers for less highly oxidized specimens. Two projects involving the study of mineral transformations have been started. In one, the factors affecting the oxidation of biotites are being investigated. Preliminary results indicated that complete oxidation is possible only when the structure is fully opened. In the other project the thermal alteration of ankerite has been investigated in collaboration with the Institute of Geological Sciences. Changes in the form of the iron occur in two stages, with complete oxidation of the iron to form a spinel-type oxide occurring at the first stage. The spinel was subsequently transformed into dicalcium ferrite in the second stage.

The oxidation and reduction of iron by fulvic acid as a function of pH has been investigated. The results were quantitatively similar to those obtained with humic acid (Ann. Rept. No. 49, 1978/79) except that reduction with fulvic acid commenced at higher pH values (*ca.* 4) than with humic

acid. A lecture on the use of Mössbauer spectroscopy in the study of plants is to be published[32]. 203, 307, 401

Electron Paramagnetic Resonance (EPR) Spectroscopy. A paper which discussed the general areas in which EPR spectroscopy can be used in soil-plant studies has been published[30] and a lecture on the use of EPR spectroscopy for the study of transition metal ions in plants is to be published[33]. 203

The work originally reported, in Ann. Rept. No. 49, 1978/79, on the uptake of V(IV) by the roots of wheat plants has been extended to include investigations of root washings, in order to characterize the species present in the free-space regions of the root. In order to help identify the chemical species responsible for the spectra obtained in Cu(II) and V(IV) plant uptake experiments, and also in studies of marine organisms (*vide infra*), further work has been carried out on the characterization of low molecular weight model complexes. A paper on Cu(II)-amino acid complexes[34] has been published, and results of investigations of Cu(II)-glycylglycine and glycylglycylglycine complexes were presented at a conference on ESR of transition metal ions in inorganic and biological systems. Other di- and tri-peptides, as well as a number of simple organic acid complexes of both metal ions, have been studied. 203, 309

Work on the characterization of metal complexes in soils has continued and a paper on the nature and origin of organo-metal complexes in soil has been published[5]. The study of the adsorption of organo-copper complexes on some minerals with a high surface area, initiated last year (Ann. Rept. No. 50, 1979/80), has continued and aspects of this work have been the subjects of papers presented at a conference on ESR of transition metal ions in inorganic and biological systems and at the Annual Meeting of the British Society for Soil Science. 203

Studies of metal ions in structural sites in minerals have continued. Some of the difficulties in interpreting spectra from powder samples, with particular reference to results obtained from Fe(III) and Mn(II) in feldspars were discussed in a paper presented at the AIPEA 7th International Clay Conference. Manganese impurities in rutile have also been investigated in both single crystal and poly-crystalline forms. In the latter samples it was possible to distinguish ions on the particle surfaces from those in the bulk of the structure. It has been shown that Mn(IV) is present at structural sites, but it has not so far been possible to determine whether the surface ions are Mn(II) or Mn(IV). 203

Further work on the characterization of free radical species present in alkali-treated soil organic matter has been carried out and these results compared with the radical species obtained from various leaf-extracts and lignins. Although a number of straightforward spectra have been obtained it has not yet been possible to identify any of the radicals specifically present. 203, 307

In collaboration with the Institute of Marine Biochemistry, work has been carried out on three projects. The studies of Cu(II) centres in

ceruloplasmin, reported last year (Ann. Rept. No. 50, 1979/80), have now been completed. In an investigation of the form and distribution of vanadium in sea squirts, which are known to concentrate large quantities of the metal, the VO^{2+} ion has been shown to be present in all species studied. In the third project the forms of copper in the blood of oysters are being investigated. So far it has been shown that a considerable proportion of the copper is present as Cu(II) bound to low molecular weight complexes. Work on model systems, see above, is proceeding with a view to identifying the chemical environment of the copper. 203

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4. SOIL ORGANIC CHEMISTRY

G. ANDERSON

The research programme of the department is mainly concerned with the origins, chemical composition and properties of the organic fractions in soil and their effects on soil fertility. The components currently being studied include the dark brown polymers, called humic substances, which are formed in soil, carbohydrates produced by plants and micro-organisms, components containing major nutrients such as nitrogen or trace nutrients such as copper, and phenolic and other organic acids which can have a physiological effect on plant growth. Experiments are carried out in the laboratory, in the glasshouse and in small field plots, and close co-operation is maintained with all other departments in the Institute. For example, in characterizing organic compounds and metal complexes, use is made of infrared and electron spin resonance

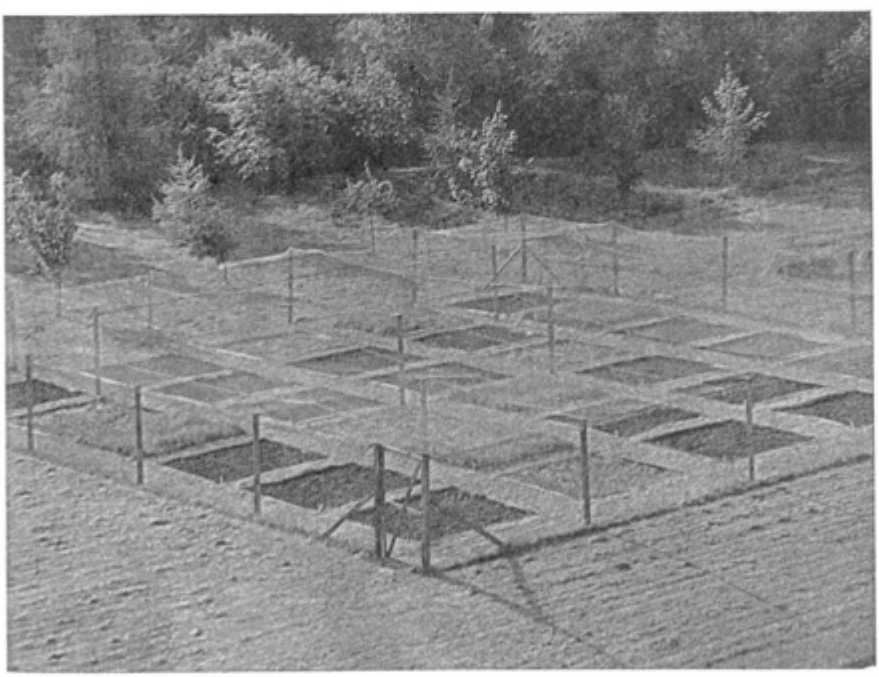

Figure 4.1
Small field plots used to monitor the levels and biological effects of soluble soil organic matter components under different crop rotations.

spectrometry in the Department of Spectrochemistry and gas chromatography-mass spectrometry in the Department of Mineral Soils. Biological effects are studied in co-operation with the Departments of Microbiology and Plant Physiology.

During the year Mr D. I. Welch completed his studies on the structure and behaviour of polymaleic acid as a model soil organic polymer and was awarded the degree of Ph.D. by the University of Aberdeen.

Soil Polysaccharide

Investigation of the relationship between aggregate stability and soil polysaccharide has continued and attempts are being made to improve techniques for measuring aggregates by sieving and sedimentation. Attempts to assess the effects of polysaccharide on aggregation are often made by examining aggregates before and after a treatment to destroy the polysaccharide. The standard method of destruction uses periodate, but it has now been shown that in soils considerable amounts of polysaccharide survive this treatment so that the effect of polysaccharides may have been underestimated in the past. The precise role of polysaccharides in stabilizing aggregates is not yet clear. 305, 512

As mentioned in last year's report, separation of soil into sand, silt and clay fractions is of some help in also separating and thus distinguishing polysaccharides of plant origin from those synthesized by microorganisms and a paper describing the results obtained has been accepted for publication[1]. In this fractionation the plant fragments, being coarser, tend to be separated along with the sand. Further work has shown that considerable proportions of the polysaccharides in some plant materials, for example fresh maize roots, are water-soluble and will be recovered along with the clay. Some of this material is starch, but part is composed of substances which yield arabinose and xylose on hydrolysis. In order to reduce contamination of the clay-bound microbial polysaccharide with plant material, the clay should, therefore, be isolated from the solution prior to analysis. 305, 512, 5613

The effects that growing plants can have on the rate of decomposition of organic residues in the soil are being examined. Barley plants grown in soil labelled one year earlier by the addition of radioactive (^{14}C) ryegrass reduced the loss of labelled carbon dioxide from the soil. About half of the conserved ^{14}C was found in the roots, chemically combined in the pectin-hemicellulose and cellulose components, and it seems likely that small organic molecules released from the decomposing ryegrass entered the barley roots and were metabolized. A paper describing this work has been accepted for publication[2]. 305, 512, 5613

In order to establish the nature of the carbohydrates produced in soil by selected organisms, soil sterilized by γ irradiation or autoclaving was treated with radioactively labelled glucose, reinoculated, incubated and the synthesized polysaccharides were analyzed[3]. During this investigation some of the glucose even in the sterile control soil was converted to a water-

insoluble form, but this was found to be caused by adsorption. Even more adsorption occurred with a peat which contains little mineral matter; the adsorbent is thought to be organic in nature. 116, 305, 512, 5613

Studies on the chemical structure of soil polysaccharide are continuing and attempts are being made to improve the method of extraction from the soil. 108, 305

A Soil Organic Model

Investigations over the last few years have confirmed that the synthetic polymer, polymaleic acid (PMA), serves as a very good model for the dark-coloured polycarboxylic acid fraction of soil organic matter and there is now little doubt that naturally derived materials with similar structural characteristics occur in every soil. Possible reasons for the exceptional stability of PMA in soil are now being examined. Using ^{14}C-labelled intermediates, a homologous series of polycarboxylic acids, ranging from succinic to hexanehexacarboxylic acid, are being synthesized. Similar polycarboxy-substituted chains exist in PMA and in natural humic substances and it has been postulated that these structural features confer stability on the polymers by promoting their adsorption on mineral surfaces[4] and by complexing metal ions in concentrations sufficient to preclude microbial attack. The radio-actively labelled acids will be incubated with the various soils used in previous studies with PMA.

One major difference of opinion between research groups in this field concerns the degree of aromaticity of humic substances. Obviously some of the precursors such as lignins and tannins are highly aromatic and it is to be expected that the composition of the raw humus of some peats, for example, will reflect this but of the results to date indicate that increasing humification involves a decrease in aromaticity accompanied by an increasing proportion of highly carboxylated aliphatic material. Recent data from workers in New Zealand, obtained by the use of advanced nuclear magnetic resonance techniques, now support this view. 304

Fungal Pigments

A paper comparing some of the properties of brown fungal pigments with those of humic acid and humin fractions isolated from a sandy soil (Ann. Rept. No. 50, 1979/80) is now being prepared for publication. 205, 301, 515

In further comparative work, ^{14}C-labelled humin was incubated with fresh soil; about 20 per cent of the radioactivity was lost after 3 months and 25 per cent after 6 months, but subsequently no further loss was detected. A similar pattern of stability was obtained with humic acid and this result, in conjunction with those already obtained from infrared spectroscopy, pyrolysis-GC and elemental analysis, indicates that humin and humic acid are closely related in terms of their structure and rate of turnover in soil. The stability of labelled pigments in soil is now being examined. 208, 301, 515

Effects of Organic Matter on Micronutrient Availability and Uptake by Plants

Investigations of the nature of the soluble metal-organic matter complexes present in soil solutions were continued. The stability constants for complexes of cupric copper and polycarboxylic acids in the soil solution have been established in collaboration with the Department of Soil Fertility. The data have been used to predict the relative amounts of free and complexed copper under various conditions of pH and ligand concentration[5]. This model shows the way in which the cupric ion (Cu^{2+}) decreases with increasing ligand concentration and with increasing pH, and indicates that under the conditions occurring in most Scottish mineral agricultural soils the concentration of Cu^{2+} will be inadequate to maintain plant growth. However, measurement of Cu^{2+} and complexed copper in various agricultural soils has confirmed that, although the concentration of Cu^{2+} is extremely low, adequate copper nutrition is sustained if total soluble complexed copper is sufficiently high. In contrast to free Cu^{2+}, total complexed copper in soil solutions is little affected by pH in the range pH 5·0 to 7·5. This contrasts with other micronutrients such as manganese, zinc and cobalt whose concentrations in soil solutions decrease with increasing pH by five to ten fold in the same pH range. It has been concluded that, of these trace elements, only copper is complexed by soluble soil organic matter sufficiently strongly to prevent its adsorption by inorganic and organic surfaces in the soil whose affinity for trace metals increases with increasing pH. 308, 5206, 5613

It has previously been found that the copper content of crops growing on soils that have been fertilized for several years with distillery wastes can be rather high. Using lucerne as a test crop in pot experiments it has now been shown that the plant copper level can be lowered by addition to the soil of peat with a low copper content, because very insoluble organic copper complexes are then formed. Large additions are required to be effective, however, and the peat also lowers the pH of the soil. Some of these results have already been discussed in the report of the Department of Spectrochemistry. 201, 307

Metal Complexes

Collaborative studies with the Department of Spectrochemistry on the interaction of iron with humic substances, using Mössbauer spectroscopy, have shown that the fulvic acid of an arable soil resembles peat humic acid in being able to reduce ferric to ferrous iron (see Ann. Rept. No. 48, 1977/78). Moreover, it does this at considerably higher pH values than is the case with the peat humic acid. 203, 307

A paper considering the possible origins of some of the metal-organic matter complexes in soil has been published[6]. 203, 207, 307

Phenolic Acids

Work has continued on the effects of phenolic acids, found in the soil solution, on the growth of several crops of agricultural importance. The magnitude of the effects is influenced to a considerable extent by the

nutrient status of the growth medium, particularly the major nutrients N, P and K. High concentrations of these can ameliorate, to some extent, the phytotoxicity of high concentrations (10^{-3}M) of the phenolic acids and enhance the stimulation of plant growth brought about by lower (10^{-5}M) concentrations. 311

Some crops, particularly potatoes, stimulate the growth in soil of phenolic acid-degrading organisms and free phenolic acids are rapidly degraded by these organisms in soil and solution cultures. The phytotoxic effects of the phenolic acids are consequently reduced in their presence[7]. 311, 512

Two papers describing the changes that occur in the biomass of soils amended with phenolic acids or glucose have been accepted for publication[8, 9]. 301, 512

Organic Nitrogen and Phosphorus

Studies are continuing on the detailed changes which occur in the organic nitrogen in soils over successive growing seasons. Only a very small proportion of the total nitrogen has a rapid turnover and attempts are being made to isolate and characterize this active fraction. In the initial stages of this investigation a considerable effort is being made to develop or improve the experimental techniques. 303

A chapter on soil organic phosphorus, in a book on the role of phosphorus in agriculture, has now been published[10]. 317

Soil Organic Matter and Plants

Work has continued on the effects of soil organic components on plant enzyme activities. Superoxide dismutase is an important enzyme which destroys the superoxide radical ($O_2^{\cdot-}$) produced in plants as a result of aerobic processes. This radical has a deleterious effect on cell membranes and its rapid destruction is, therefore, essential. Humic substances, particularly humic acid, enhance the activity of superoxide dismutase and hence accelerate the destruction of the radical. A paper dealing with this work, and on the effects on xanthine oxidase mentioned previously (Ann. Rept. No. 50, 1979/80), has now been accepted for publication[11]. 311

Humic substances labelled with ^{14}C have been used to examine the uptake of these soil components by plant tissue. After 18 hours of culture under axenic conditions, excised pea roots took up more fulvic acid than humic acid. The soil organic matter was adsorbed on the root surface and cell walls, but uptake was also due to a mechanism dependent on metabolism, particularly protein synthesis. Gel chromatography showed that the humic acid consisted of two discrete molecular size fractions, one greater than 50,000 daltons, the other less than 2,500 daltons, both brown in colour. In contrast only one fraction, less than 2,500 daltons, was obtained from the fulvic acid. The larger molecules were taken up only by adsorption, but the smaller, from both the humic and fulvic acids, were taken up by both mechanisms. An account of these observations has been published[12]. 311

Effects of Light on the Growth and Development of Seedlings

Collaborative work in this field with Dr J. W. Hart, of the Botany Department, University of Aberdeen, has continued.

A miniature growth chamber in which seedling plants can be accommodated in various orientations with respect to gravity and under irradiation regimes differing in light quality, quantity and direction has been designed and constructed with assistance from Technical Services. Used in conjunction with time-lapse photography, it permits the comparison of seedling growth under varying conditions of stress in which the growth kinetics may be determined with a high degree of precision and accuracy. A paper describing the apparatus and experimental approach has been submitted for publication[13]. This paper also reports the results of a comparative study of the growth of green and etiolated cress seedlings in white light and darkness showing the location of growth regions in the two types of seedling and their differing response to light. In the dark, growth in green seedlings occurs over a more restricted region than that in etiolated seedlings. Although light further restricts the region of growth, the immediate response to light

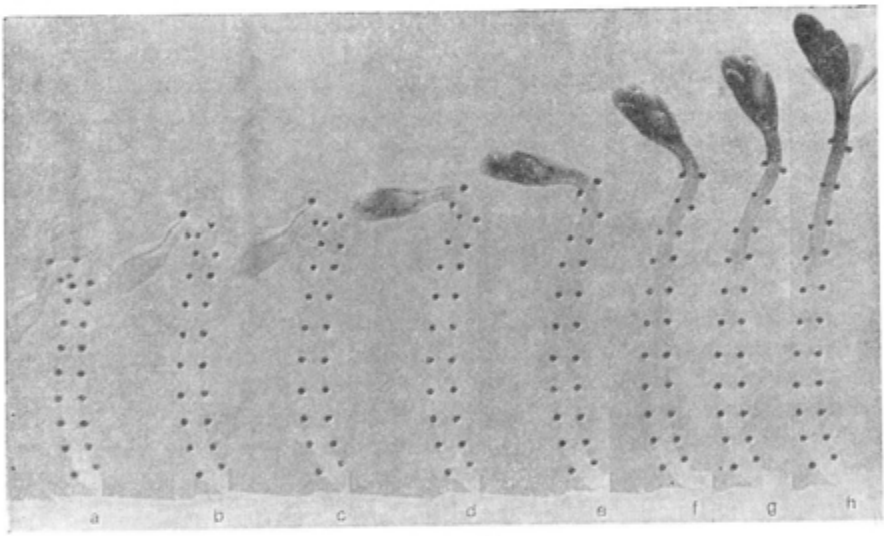

Figure 4.2

Time-lapse photography of hypocotyl hook opening in an etiolated cress seedling during exposure to white light following growth in darkness. (a) zero time, (b) after 4 h in darkness, (c) to (h) after 1, 3, 4, 6, 9 and 18 h exposure to white light. The application of small beads enables growth in a particular zone to be monitored.

differs in green and etiolated seedlings, the latter showing a stimulation of growth in the apical zone in contrast to the former in which light inhibition is initially most prominent in the uppermost region. This distinction is due, at least in part, to the influence of light on the opening of the hypocotyl hook in etiolated seedlings. 309

The opening of the hypocotyl hook (Fig. 4·2), a development of critical importance in the successful establishment of the seedling plant, has been

investigated using the same experimental approach. In this study, a report of which has been submitted for publication[14], it has been demonstrated that the opening of the hook is the result of a light-induced acceleration of growth in a region in which growth in the dark is negligible.

However, this is accompanied by inhibition of growth in closely adjacent regions, a response which presents a considerable challenge to the commonly accepted view that a gradient of a single growth substance regulates seedling growth (see Ann. Rept. No. 50, 1979/80). 309

Further evidence against the concept of growth regulation by a single substance has been obtained in a related study of the kinetics of growth curvature in unilateral light in which curvature apparently arises from an integrated sequence of changes in growth rate involving both inhibition and stimulation on each side of the organ. The extent to which inhibition or stimulation predominates at a given time can vary according to whether the seedling was previously in the light or in the dark, and the indications are that the degree of response is not simply a characteristic of the species. An account of the work has been submitted for publication[15]. 309

Papers referred to in last year's annual report dealing with the interaction of geotropism and phototropism[16], the phototropic responses of green and etiolated seedlings[17] and the effect of light on mustard seed germination have been published[18]. 309

Other Investigations

Collaboration has continued with the Department of Plant Physiology on their studies of the duckweed *Lemna gibba L*, and a paper dealing with changes in the activity of the enzyme superoxide dismutase in *Lemna* grown in zinc- and copper-sufficient and deficient media has been accepted for publication[19]. Superoxide dismutase is present in the fronds of *Lemna* where about 90 per cent of the enzyme is concentrated in the soluble fraction remaining after the cells are centrifuged at 140,000 *g*. It was established that the enzyme is a Cu-Zn metalloprotein of molecular weight 31,500 daltons. In Zn-deficient media, the enzyme activity was only half that present in fronds grown in the complete nutrient medium whereas in Cu-deficient plants there was little change in enzyme activity when compared with the controls. The addition of ionic Zn to superoxide dismutase preparations from Zn-deficient plants restored the enzyme activity to the level found in the *Lemna* grown in complete nutrient media. 311, 401

A paper dealing with the effects of the soil fumigant Dazomet on phenolase activity in exudates produced by the plant pathogen *Sclerotinia sclerotiorum* has now been published[20]. 301, 515

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5. PLANT PHYSIOLOGY

P. C. DeKock

Interrelationships of the major and minor elements in plant growth has been the major topic of research, but the special interest in calcium deficiency in horticultural crops and the involvement of waterlogging in the disorder has meant that a considerable part of departmental effort is now directed towards practical solutions.

Calcium Deficiency

1. *Carrot Cavity Spot*

Although the field experiment at Stockbridge House EHS gave equivocal results at the final harvest, it showed at the beginning of the period that nitrate-fed carrots were free of blemishes whereas those fed ammonium-nitrogen were affected. However, as 1980 was exceptionally wet and as no further additions of nitrogen were made, at the December harvest all carrots were affected irrespective of treatment. New experiments have been laid down at Stockbridge House and also in Norfolk, but due to the dry and sunny summer, carrots show little signs of the disorder. However, recent wet weather may change the position, but it is apparent that split dressings of nitrogen have improved yields; in some cases yields have doubled. A paper on earlier work is in press[1] and a report of further work is in preparation. A simple diphenylamine test for nitrate in field crops has been devised and kits have been supplied to various research stations. A specialist officer has been appointed by ADAS to study nitrate levels in carrots in Norfolk, using this technique.

2. *Tomatoes — Blossom-end Rot*

Irregular water supply has been considered an underlying cause of BER, but studies made over the last two years have shown that plants under water stress may take up more calcium than plants with an adequate water supply. Calcium deficiency will occur if localised soil moisture tension is sufficient to precipitate calcium salts from the soil solution, while potassium salts remain in solution. However, it has been shown that the source of nitrogen —whether ammonium or nitrate—still has the over-riding effect on the occurrence of BER. This work is to be published[2].

A further cause of BER was highlighted by growers in Guernsey removing successive trusses from plants in the expectation that these would mature at periods of glut, whereupon successive trusses were all affected. Earlier experiments here had shown that truss trimming induced BER. This has been repeated and the results submitted to the press[3]. The explanation rests in our earlier demonstration that cytokinins increase the

ratio of potassium to calcium. Cytokinins such as zeatin and zeatin riboside are produced by tomato roots so that fruit-trimming causes excessive amounts of these hormones to move into the remaining fruit.

3. *Brussels Sprouts — Internal Browning*

A solution to IB in Brussels sprouts appears difficult as it is the larger sprout which exhibits IB, probably due to enhanced amounts of cytokinins from the roots[4]. Healthy and affected sprouts may occur randomly distributed over the stem. Experiments in conjunction with the North of Scotland College of Agriculture's Department of Horticulture are in progress. A note on the common biochemical background of calcium deficiency disorders has been published[5] and work is progressing on the mechanisms of cell wall necrosis. 402, 408

Trace Elements

Iron: A review paper on iron stress presented at the International Symposium on Trace Element Stress held at the University of California at Los Angeles has been published[6]. Considerable international interest has been created by this paper. An account of earlier work using the stable isotope ^{57}Fe was presented at the ESNA conference in September[7].

Copper: Work on the amino acid composition of oat straw under copper stress has been presented for publication[8]. Work on superoxide dismutase in relation to copper and zinc nutrition of *Lemna gibba* has been accepted for publication[9]. The relations of this enzyme to cellular metabolism are being further investigated, with special reference to the interrelationships of copper and zinc with cadmium. Studies on the amino acid composition of Alyssum species in relation to nickel tolerance are being written up[10].

Selenium: Work of previous years is being written up. A poster display was presented at the ESNA Conference at Aberdeen in September. 401

Calcium flux and transport studies

In an earlier Annual Report (No. 47) an account was given of flux studies on cortical cells of onion root segments using a nutrient solution varying only in the concentration of the calcium salt, to give a range of treatments from 1 μM to 10 mM calcium. It was suggested that at external Ca^{2+} concentrations of between 0·01 and 0·1 mM, calcium flux appeared to be in passive equilibrium in contrast to the active efflux found at higher external concentrations. When the external Ca^{2+} concentration was at the lowest level (1 μM), Ca^{2+} absorption appeared to occur against an electrochemical potential gradient, implying the activity of a calcium influx pump.

More recently we have come to the view that Ca^{2+} activity in the cell cytoplasm was possibly much lower than the compartmental analysis of ^{45}Ca exchange indicated, and more of the order of magnitude found in animal cells (10^{-7}M). In this circumstance, the apparently high exchange of calcium across the plasmalemma would be explained in terms of short residence times for ^{45}Ca " bound " in the cytoplasm. The results have now been reassessed from this point of view. This has led to the conclusion

that, at all external Ca^{2+} concentrations examined, calcium uptake to the cytoplasm is passive and the cytoplasm Ca^{2+} concentration is maintained at much less than equilibrium level by the activity of an efflux pump across the plasmalemma, and an influx pump across the tonoplast to the vacuole. A full account of this work has now been published[11]. 407

Studies using amino-acid analogues

These compounds are used to produce non-functional proteins in place of the normal proteins considered to be involved in the transport of ions to the shoot, following uptake into the root. The range of analogues used has been extended from DL-parafluorophenylalanine alone, to include the ortho- and meta- isomers of this amino-acid, and also L-azetidine-2-carboxylic acid (AZ). The effects of these analogues on ion uptake and transport have been tested using intact wheat seedlings in the light, but in conditions very close to 100% RH, so that transpiration was negligible. K^+, Na^+ and Ca^{2+} uptakes were unaffected by any of the analogues, but transport of K^+ and Ca^{2+}, as estimated by the appearance of radioactive isotope in the shoot, were reduced significantly by all the analogues, and most severely by AZ. This is in contrast to the findings with root segments reported earlier (Annual Report No. 50). Sodium transport was negligible even in the control. Both uptake and transport of chloride were affected to varying degrees by all the analogues used.

The striking way in which cation uptake was largely unaffected by amino-acid analogues indicates that the uptake step is different from the transport process for cations and seems to be independent of protein synthesis. The results also provide further evidence for the specificity of the analogues, as far as cation transport is concerned. 407

Potassium absorption and transport

Further studies on the effects of synthetic crown ethers on potassium uptake and transport in wheat seedlings, in collaboration with the Department of Molecular Structures, Rothamsted Experimental Station, have involved the use of tertiarybutylbenzo-18-crown-6. This crown compound was found to be inhibitory of K^+ uptake and growth at lower concentrations than were found effective for benzo-18-crown-6. However, at the highest concentration tested (0·3 mM), although root content of K^+ was further reduced, a marked increase in K^+ content and concentration in the shoot was observed, compared with levels found in the presence of 0·1 mM crown. This suggests that at a certain level of tertiarybutylbenzo-18-crown-6, K^+ uptake is stimulated, but that this increased quantity is channelled exclusively to the transport pathway to the shoot. This phenomenon offers further prospects for study. 407

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6. MICROBIOLOGY

J. F. Darbyshire

The role of microorganisms in soil metabolism, particularly close to plant roots, is the main theme of the research programme of this department. Microbiological projects form most of research package 5 of the Institute.

Interrelationships of Plant Roots and Microbes

A paper discussing the reasons why the acetylene reduction test is unsuitable for estimating the activity of nitrogen-fixing bacteria associated with the roots of cereals has been accepted for publication[1]. Nitrogen balance and ^{15}N dilution experiments in sand or soil have indicated that the significance of nitrogen-fixing bacteria, associated with wheat roots, to the nitrogen nutrition of British and Canadian cultivars is negligible in temperate climates. This conclusion applies to bacteria in the rhizosphere and either in or on wheat roots. The major factor limiting nitrogen fixation associated with cereal roots appears to be a shortage of carbohydrate in the root region. Isotope dilution experiments with ^{15}N in sand, using 99% ^{15}N labelled seeds, calcium nitrate and microbial inocula showed that when extra carbohydrate was added to the root zone, aerobic (*Azotobacter beijerinckii*), microaerophilic (*Azospirillum brasilense*) and facultative anaerobic (*Bacillus polymyxa*) nitrogen-fixing bacteria were capable of fixing nitrogen in the wheat root environment and some of the fixed nitrogen was transferred to the tops of the plants. Indirect evidence suggests that the microbially-fixed nitrogen does not become available to wheat roots until death and lysis of the microbes have occurred. Some of this work has been reported at meetings in Aberdeen of the British Soil Science Society and European Society of Nuclear Methods in Agriculture. A detailed account is now being prepared for publication. 514

The production of axenic barley, wheat and maize growing in soil and within a $^{14}CO_2$ growth chamber has enabled the movement of labelled root exudates into the soil to be measured and the contribution of soluble plant materials to various soil fractions to be estimated. The soil and plants were used subsequently in organic matter studies. 305, 513, 5613

The growth of nutrient-deficient tobacco plants was greatly improved when the root medium was amended with yeast cells (*Lipomyces starkeyii*). The plant growth responses were related to the degree of nutrient deficiency and the size of the microbial inoculum. It appears that tobacco plants can easily utilise nutrients from living microbial cells. Further experiments are planned on nutrient cycling between microorganisms and plants. 513

Fungi

Ultrastructure. The joint project with the Department of Soil Organic Chemistry on the ecology and physiology of phenolic acid-degrading fungi, isolated from the soil close to roots of several agricultural crops, has continued. A paper describing morphological features of one of the isolates, *Volutella ciliata* has been published[2]. Cryo-fixation was used to demonstrate clearly the fringe of setae around the fructification (sporodochium) of this species. The identification of this fungus was confirmed by the Commonwealth Mycological Institute and a culture has been deposited at the American Type Culture Collection (accession No. ATCC 44365). Another fungus isolated during these studies, *Stilbella bulbicola*, has antagonistic properties towards other soil fungi (*Penicillium* sp. *Botrytis allii*, *Trichoderma viride*, *Mucor ramannianus*, and *Aspergillus niger*). Preliminary studies suggest that this antagonism is due to a pH effect rather than to the production of an antibiotic (Fig 6·1). *Volutella ciliata* was also

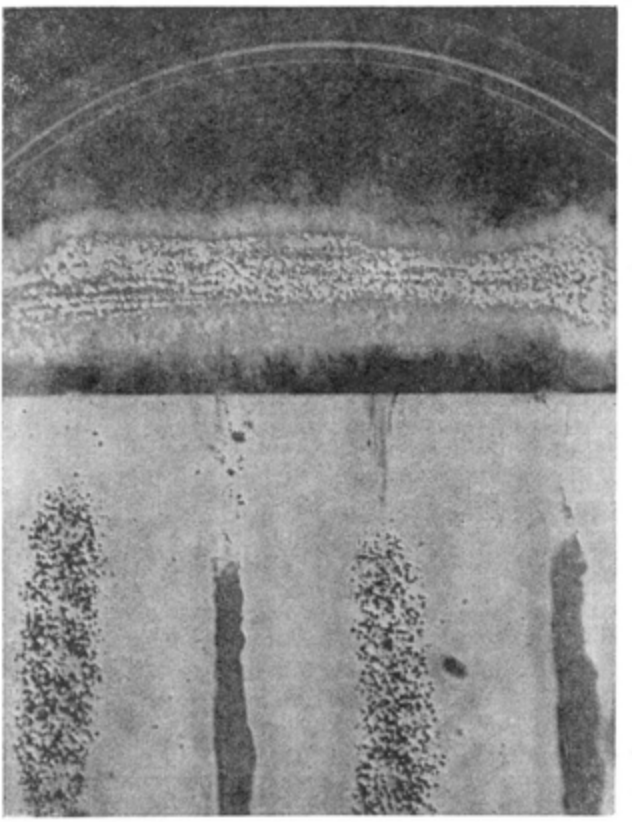

Figure 6.1

The soil fungus, *Stilbella bulbicola*, in the upper part of the Petri dish exhibiting antogonism to mycelia of *Aspergillus niger* and *Penicillium* sp. in the lower part of the dish. Note zone of inhibition in the middle of the dish.

antagonistic towards *B. allii*, but in this case the effect does not appear to be due to pH changes in the agar. The morphology of the soil fungus, *Acremoniella velata* sp. nov., also isolated during studies in the degradation of phenolic acids, has been reinvestigated with the critical point drying technique. A joint paper with the Curator of the Commonwealth Mycological Institute describing some of the unusual spores of this fungus has been accepted for publication[3]. 516

Melanins. A paper dealing with the possible contribution of melanin pigments to the humin fraction of soil is being prepared for publication. This joint project with the Departments of Soil Organic Chemistry and Spectrochemistry should help to explain why certain fungi, especially the darkly pigmented forms, persist in soil for relatively long periods.

208, 301, 515

Protozoa

Morphology and Ecology. The movement of the amoebo-flagellate described previously (Annual Report, 1979/80) has been studied using cine-microphotography. The flagellates move (1·5-3·0 μm/sec) at least one order of magnitude faster than the amoebae. This greater mobility appears to be due to faster amoeboid movement rather than to movement of the flagella, which appears to function as tactile organelles. Ultrastructural evidence from the flagellate phase suggests that this amoeboflagellate belongs to either the subclass Protosteliia with affinities to the family Cavosteliidae or to a heterothallic member of the subclass Myxogastria. Further indentification is dependent on the development of sporocarps. Similar cinemicrophotographical studies of 2 members of the Cavosteliidae (*Cavostelium bisporum* and *Planoprotostelium aurantium*) have shown that the flagellates also move at least one order of magnitude faster than the corresponding ameoboid phase. In both species the flagella seem to function solely as tactile organelles. The flagellates of *C. bisporum* move at about 0·9 μm/sec in liquid media; the corresponding speed for flagellates of *P. aurantium* is 0·6 μm/sec. These observations are being prepared for publication. 510

Organic Matter

Microbial decomposition and synthesis. The rate of decomposition of ^{14}C-labelled soil organic matter was shown to be reduced in the presence of a barley plant[4]. About half of the reduction was accounted for by direct uptake of ^{14}C compounds by the plant; radioactive label was detected in structural carbohydrates of the cell walls of the root, but very little radioactivity occurred in the shoot. The reason for the rest of the reduction in decomposition is unkown, but it does not appear to be caused by drier soils and lower microbial activity in the presence of the plant. One paper has been published on the synthesis of polysaccharides in soils by selected microorganisms[5] and work is continuing on the distribution of microbial and plant polysaccharides within various soil fractions. Microbial products appear to be concentrated in the silt and clay fractions of the soil, but a high

proportion of apparently undecomposed plant residues is associated with the sand fractions. These results were presented at the autumn meeting of the British Society of Soil Science. 305, 512

Microcalorimetry. Further work on the use of microcalorimetry to monitor microbial activity in soil has confirmed that large increases in heat output follow amendments with substrates[6]. In amended soils there was a consistent relationship between the biomass and the rate of heat output (lg biomass$\simeq$180 mW) immediately after the addition of glucose. Other microcalorimetric data suggest that catabolism in the soils was largely aerobic and that rates of catabolism of the biomass of non-amended soils are comparable with the endogenous metabolic rates of microorganisms in pure culture. Storage of soils alters the relationships between biomass, rates of heat output and respiration, probably because of the altered proportions of active microbes and the changing enthalpy of the substrates utilised. A poster summarising these results was presented at the British Soil Science Society meeting in Aberdeen. 512

Phenolic acids. Two papers, dealing with the degradation of soil phenolic acids and the effects of these acids on plant growth in the presence or absence of phenolic acid-degrading microorganisms, have been published[7, 8]. The beneficial effects of microorganisms in degrading phenolic acids in soil and reducing the toxicity of these acids to wheat were reported at a meeting of the Society of Chemical Industry in London. 311, 512, 513

Polysaccharides. The effects of soil polysaccharides from plants and microbes on soil structure is being investigated in collaboration with the Department of Soil Organic Chemistry. Improved methods for determining aggregation are being developed and existing methods for measuring polysaccharides in soil aggregates have been modified.

Biomass. Two papers on the biomass and activity of microorganisms in glucose-amended soils have been published[9, 10]. The role of the biomass in the long term maintenance of fertility of peaty soils is also being investigated in a collaborative study with the Department of Peat and Forest Soils. The usual methods of measuring biomass in neutral mineral soils give very anomalous results when applied to peats and have required some modification. Using the substrate-amendment method to estimate biomass, a positive relationship was discovered between the size of the biomass and the concentration of mineralizable nitrogen in peaty soils. Investigations into the turnover of biomass and the source of a long term supply of mineral nitrogen in peats are continuing. Short collaborative studies were undertaken with other laboratories (Rothamsted Experimental Station; State Laboratory for Soil and Crop Research, Lyngby, Denmark; Glasshouse Crops Research Institute) on soils and mushroom composts. In general, there was good agreement between the various methods used to measure biomass in the different laboratories. These results are being prepared for publication. 116, 301, 512, 513

Biological Weathering

Studies of the microbial weathering of rock-forming minerals by fungi from rhizosphere soil, e.g. *Penicillium oxalicum*, and lichens have continued with the Departments of Mineral Soils and Spectrochemistry. The techniques used in these studies, such as scanning electron microscopy, X-ray microanalysis and X-ray powder diffractrometry, have proved of interest to a diverse range of research workers. For example, requests for information have come from persons concerned with lichens disfiguring Mayan ruins in Central America (Department of Botany, Smithsonian Institution, U.S.A.), lichens weathering ancient monuments in Spain (Centro de Edafologia y Biologia Aplicado del Cuarto, Spain) and lichens encrusting mica-schist in the Antarctic (British Antarctic Survey, Cambridge). Recently, staff at the British Museum (Natural History) have reported the occurrence of Weddellite crystals of calcium oxalate, similar to those detected at the rock-lichen interface (Annual Report, 1979/80), in association with lichens on a 800-year-old bone from an archaeological site in the High Arctic. Two papers dealing with aspects of serpentinite weathering by the encrusting lichen, *Lecanora atra*[11], and of basalt weathering by *Pertusaria corallina*[12] have been published. During these studies, the mycobiont in the lichen *Pertusaria corallina* and a dematiaceous fungus, *Sclerococcum sphaerale*, which was growing on this lichen, were obtained in pure culture. Both fungi are very slow growing in agar culture but, unlike the mycobiont, the dematiaceous fungus does not appear to secrete oxalic acid. Very few obligately lichenicolous Hyphomycetes have been grown in pure culture. This fungus is the subject of a joint publication with Dr D. Hawksworth, of the Commonwealth Agricultural Bureaux[13] and a culture has been deposited at the Commonwealth Mycological Institute (accession number IMI 247000). Some aspects of this work were referred to in a lecture by Dr Hawksworth at the 12th International Botanical Congress in Sydney.

The relevance of lichen weathering to pedogenesis in cool temperate climates was discussed in a lecture by Dr M. J. Wilson at the Geological Society in London and is the subject of a joint paper which has been accepted for publication[14]. Another paper describing the application of scanning electron microscopy and microprobe analysis to studies of lichen weathering of rock-forming minerals has also been accepted for publication[15]. A poster on the same subjects as these two papers was displayed at the Aberdeen meeting of the British Society of Soil Science.

104, 109, 207, 516

A paper describing the use of a bacterial exudate, 2-ketogluconic acid (2-KG), as a soil extractant for the diagnosis of trace element deficiencies or toxicities has been submitted for publication[16]. Previously (Annual Report, 1959/60), 2-KG from soil bacteria had been shown to solubilise various soil minerals. 201, 202, 502

Peat Microbiology

The distribution of anaerobic bacteria in a deep peat bog at Lyne of Skene near Aberdeen is discussed in a paper submitted for publication[17].

The first stage of a collaborative study with the Department of Peat and Forest Soils on the bacteria in peat samples from the controlled water table experiment at Lon Mor near Fort Augustus has been completed. The largest populations of aerobic and anaerobic bacteria occurred near the surface and there was a decline in numbers of both groups of bacteria with depth in all the plots. Drainage led to an increase in the numbers of aerobic bacteria in the horizons above the water table but did not greatly affect the numbers of anaerobes in the same horizons. Below the water table, the

Figure 6.2
The distribution of sites with serious iron ochre (●) and white microbial deposits (△) in field drains during a 1977 survey. The survey was only a partial one, *e.g.* there was virtually no investigation in most of the West coast or central regions of the land mass of Scotland.

populations of both anaerobic and aerobic bacteria were largest in those plots with the lowest water table (34 cms below the surface) and could be ten times larger than the same horizon in the undrained plots. The great majority of the isolates were proteolytic. A significant proportion of the bacteria could utilise ammonium salts as their sole source of nitrogen and this proportion was larger in the well drained plots. Only a small number of isolates could utilise nitrate, although the numbers of aerobic bacteria in this category were also higher in the well drained plots. Nitrogen-fixing bacteria, determined by the acetylene reduction technique, greatly increased in the horizons above the water table after drainage. 116, 503

A survey of drained peatlands showed with the help of staff from DAFS and the three Colleges of Agriculture that field drains blocked by the deposition of red ochre is a widespread problem in Scotland (Fig. 6·2). A microbiological study of a local example of this problem at Keithen Farm, near Turriff, has started. 116, 503

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7. SOIL FERTILITY

B. W. Bache

The Department's work for the period of this report has continued on similar lines to that in previous years, although we are currently reassessing our objectives and planning new developments. One barrier to their execution is shortage of staff, made more acute by the resignation of Dr G. D. Buchan to take up a lectureship in physics at Strathclyde University, and of several support staff.

The Department has been represented on the Scottish Standing Committee for the Calculation of the Residual Value of Fertilizers and Feeding Stuffs, the Consultative Committee for the Development of Spectrochemical Work, the COSAC-SARI Trace Element Study Group and the COSAC-Macaulay Liaison Group.

We are pleased to welcome Dr R. Lee from the Soil Bureau, Lower Hutt, New Zealand, for 15 months study leave to work on aluminium in some New Zealand soils. S. D. Young completed his research studentship on aluminium-organic interactions, and M. Hepher and Miss S. Fraser are research students working on the development of piezoelectric crystal gas monitors supervised by the Director and Dr T. E. Edmonds.

Field Crop Studies

Nitrogen for Barley. Abnormally high rainfall during the autumn of 1980 caused excessive leaching of soil nitrogen, so that responses to N were higher than normal in both autumn sown barley (Igri) and spring sown barley (Golden Promise). Our experiments confirm that winter barley requires more N than spring barley. Thus three winter barley trials gave maximum yields with 150-170 kg/ha N and in three others the response was still linear at 160 kg/ha N, whereas five trials on spring barley required only 110-120 kg/ha N for maximum yield. These rates are for spring top dressings of N, and in the winter barley experiments smaller amounts of N were also used in the autumn by the resident farmers. 607, 608, 5701, 5703

Average yields at optimum N rates in 1981 were generally similar for winter and spring barley. In over 50 experiments on spring barley in recent years, maximum yields have not exceeded 6·5 t/ha of grain dry matter. However, at one site ploughed out of a grass-clover ley winter barley yielded 8·2 t/ha grain dry matter (9·6 t/ha at 15% moisture) indicating that this crop has greater yield potential. A high level of management expertise (early sowing and effective weed and disease control) combined with the good environmental conditions of the season contributed to this

high yield. Experiments are continuing on the date of sowing and the need for supplementary autumn and early spring N applications, in addition to the main spring N requirement. 607

Recent work in the Department has shown that barley plants at the 6th leaf stage should contain at least 4·5% N if yield is not to be reduced by shortage of N, but the shortfall can be made good by N top dressings if they are applied soon. To use this information for advisory work would produce an impossible analytical burden, so rapid indirect methods for indicating plant N contents are being investigated. Soluble nitrate in plant tissue has been found to be unreliable. Chlorophyll content correlates well with total N, but at present its estimation is not much more rapid than conventional N analysis. Near infra red (NIR) reflectance analysis is another possibility, but although the analysis is rapid, it still requires drying and milling of the plant material. Tests in cooperation with the Scottish Crop Research Institute (Pentlandfield) have shown good agreement between total N in young barley plants and their N content deduced from NIR reflectance analysis. 606

Developmental Physiology of Barley. A comparison of the growth patterns of autumn- and spring-sown barley demonstrated the higher yield potential of the former at higher N levels. The most obvious difference between the crops appeared to be the survival of tillers during the ear emergence phase. In spring barley, any tiller which is pale in colour and at an early stage of stem extension will almost certainly fail to produce an ear. Thus all fertile tillers will appear within about 10 days of the start of ear emergence. In winter barley, however, ear emergence started on 20 May and ear number/m^2 continued to increase until late June. An important practical consequence of this pattern of development is uneven ripening: the crop may be harvested with a large proportion of unripe grains resulting in high drying cost, or the crop can be left until most grains are ripe which may result in loss of grains from overripe ears. 607

Periodic samplings of spring barley from field experiments over the past six years has shown a progressive increase in soluble carbohydrate up to ear emergence followed by a decline in the carbohydrate content of the straw as the grain fills. Winter barley sampled in April, however, was found to have a much higher carbohydrate content (%) than spring barley at that time, although the subsequent form of the curves suggested that both crops had very similar metabolisms, only displaced in time due to the earlier sowing of the winter barley. Similar effects occurred with excess base and nitrogen in the two crops. 606

Nitrogen-Soil pH Interactions for Barley. The 1981 experiment again showed no significant yield increase at pH 6·2 (in water) compared to pH 5·6, with additions of 100 kg/ha N, but yielded 6·4 t/ha grain dry matter compared to 4·0-4·5 t/ha in previous seasons. This shows that soil pH values below 6·2 can still give high productivity when other growth limiting factors have been alleviated. 607

Minimum Cultivations for Barley. The experiment begun in 1975 to compare broadcast and combine drilled phosphate with three cultivation

methods, normal ploughing, chisel ploughing and no ploughing (direct drilling), was completed in 1981 with a winter barley crop. As in previous years there was a small response to phosphate, and the no-P plots were slower to ripen than the high P plots. The method of applying phosphate gave no difference in yield, in contrast to previous years when combine drilled phosphate was slightly superior for spring barley. For the first time, however, the no-ploughing plots gave a higher yield than the other cultivation methods, showing that direct drilling may be a viable practice for winter barley, provided there is adequate weed and disease control.

608, 5701, 5703

Copper for Herbage and Barley. Further measurements have been made in four experiments of the residual effects of copper applied as copper sulphate or copper oxychloride. On these copper deficient soils the copper treatments continue to produce small to moderate increases in the yield of spring sown barley even after 5 years and in the copper content of crops, the increases in copper content being greater in young barley plants and herbage than in mature cereal grain and straw. Winter barley was grown in one of the experiments and the yield of grain was slightly increased by the copper residues. 609, 202, 5701, 5703

It has been suggested that significant reductions in cereal grain yield during copper deficiency may be caused by the level of carbohydrate in the plant and its translocation into the grain. Barley plants from five copper experiments have been analysed for reducing sugars and total soluble carbohydrates. In samples taken up to and including ear emergence there were no differences in carbohydrate content between plants from nil copper plots and from plots to which copper had been applied. There was thus no evidence of any lack of carbohydrate in these barley plants, but measurements still have to be made on the straw during grain filling to see if translocation differences exist. 606

Boron for Potatoes. Eight experiments were carried out during 1978-1980 to measure the effect of borax applications on the yield and boron content of potatoes. In one experiment applying boron increased the yield by about ten per cent, but there was no response in other experiments where the water-soluble boron was only about 0·5 mg/kg soil, and a slight reduction in yield with high soil boron. The fully grown potato haulms contained about 25 mgB/kg dry matter and boron additions of 3 kg/ha produced increases from 0 to 15 mgB/kg. The potato tubers contained 5 to 10 mgB/kg and applied B increased this by less than 1 mg/kg. There was no evidence of internal browning when tubers from the no B treatments were cut in half. Thus at present there appears to be no need to apply boron to potatoes in Scotland even on soils considered deficient in this nutrient for brassica crops. 609, 5701, 5703

Lime and Nutrients for Herbage on Peat. A short paper summarizing the main findings from the experiments carried out during 1973-1977, which were also described in the 50th Annual Report, has now been published[1].

Nitrogen for Grass and White Clover Swards. The collaborative ADAS/ARC grass-white clover experiment (GM 23) was completed in 1981 after

4 years. The results for 1980 were similar to previous years, with Blanca white clover showing no yield superiority over S 100 in the ryegrass mixtures without added N. Graphical estimates of fixed N for three years 1978-80 were about 170 kg/ha from Blanca and about 195 kg/ha from S 100. The residual effects of the ley will be tested on winter wheat in the coming season. 603, 609, 5701, 5703

Sulphur for Various Crops. Of two experiments on potatoes in 1980, one gave a 10% yield increase to sulphur applied either as potassium sulphate or as gypsum, but the other gave no increase. The phosphate-extractable sulphate levels of the two soils were 4 and 7 mgS/kg respectively. Two experiments on Swedish turnips on soils with 5 mgS/kg gave a small increase in shaws but no clear increase in yield of roots; these swede experiments are being repeated in 1981. Three experiments in 1980 with herbage on low sulphur sites (phosphate-extractable sulphate about 6 mgS/kg) gave increases in herbage yields of 10-15% at the second and third cuts on plots where sulphur had been applied with 60 kgN/ha or more for each cut, but there was no sulphur response in the absence of applied N. A similar pattern is being shown in the 1981 experiments. On low sulphur soils, sulphate additions may thus be needed to obtain the optimum benefit from applied N for cutting or grazing after a first cut for silage or hay, but further experimental work is needed to define the situation more precisely. (See also under Soil Chemistry.) 601, 608, 5701, 5703

Physiological work on swedes. The experiments in 1980 on the effects of plant population and its interaction with N and P on the growth and yield of swedes, are being repeated in 1981. The earlier results indicated that root and leaf growth were reduced, particularly in the later stages of growth, at populations of 100,000 plants/ha. Populations of 50,000 plants/ha increased root growth in the early stages of development, but this was offset by reduced growth and more rapid leaf senescence later. There is no evidence that populations higher than the recommended 50-60,000 plants/ha would be beneficial. 607

Studies are continuing on changes in nitrogen, organic acids and carbohydrates of swede leaves during growth in order to understand how nitrogen affects dry matter assimilation in this crop. 606

Manganese Deficiency in Barley. Experiments on two sites prone to manganese deficiency tested for spring-sown barley the effects of seedbed compaction, method of fertilizer application, and spraying with $MnSO_4$, on the yield, the manganese content and the grain quality expressed as grain specific weight in kg/hectalitre. The soils had initial pH values (in $CaCl_2$) of 6·0 and 5·7. The Mn content of barley plants at 4-5th leaf stage was increased both by compacting the seedbed, and by combine drilling NPK fertilizer rather than broadcasting it. There was a positive interaction between these effects, and the overall increases were from 13 to 19μg Mn/g dry matter at one site, and from 13 to 28μg Mn/g at the other. These increases in crop Mn contents were associated with a decrease in rhizosphere pH of 0·5, which is probably the main explanation for considerable increases in soluble and extractable Mn in the rhizosphere soil. Combine

drilling of the fertilizer had more effect on grain specific weight (increased from 62·3-64·3 kg/hl) than had the other treatments. The main effects on grain yield in t/ha dry matter, are summarized in the following table:

	$MnSO_4.H_2O$ added:	0		4·5 kg/ha	
	Seedbed:	loose	compact	loose	compact
Yield t/ha	NPK broadcast	3·6	4·5	4·6	4·6
	NPK combine drilled	4·8	4·8	5·0	5·2

These results illustrate that nutrient supply to crops must be related to soil physical conditions and management practices, rather than considered in isolation. 609

The effects of foliar sprays of $MnSO_4$ and Mn chelate were measured on four spring barley crops on soils with pH (in $CaCl_2$) between 5·8 and 6·1. Responses of 0-0·5 t/ha grain dry matter were given by 4·5 kg/ha of $MnSO_4$ in 225 litres water, and of 0-0·2 t/ha from MnEDTA chelate at the manufacturer's highest recommended rate. The quality of the crop as reflected by grain specific weights (64-66 kg/hl) was unaffected by the Mn spray treatments. 609

Soil Physics

Soil Energy Balance. The work on the prediction of bare soil temperatures from standard meteorological data, described in previous reports, has now been brought to a conclusion[2, 3, 4]. The final part of the work extended the general model developed for means over a many-day interval, to single-day diurnal variations in temperature. To do this it was necessary to replace the approximate assumptions of periodicity in the input meteorological functions and of constant mean 24-hour temperatures, with a linear ramp term to account for the non-cyclic changes in surface temperature and to specify the initial condition of the soil temperature profile. The model was tested against experimental measurements of soil temperature in spring and in autumn, and the agreement between observed and predicted temperatures was very close, with the highest value (0·5°) of the mean deviation occurring at the surface. 612

Physical Measurements for Soil Series. It has been suggested that mean values of simple soil physical properties such as bulk density, available water and drainable pore space should be reported for soil series. To assess how meaningful this would be, the variation of these properties both within-series and between-series has been estimated. Some series were remarkably uniform in physical properties, but others were highly variable. This work has been described in previous Annual Reports and has now been published[5]. The measurements are being extended to further soils, in co-operation with the Department of Soil Survey, and will become an integral part of soil survey information in the future. 612

Soil Chemistry

Potassium. Work on the release of potassium from soils of contrasting mineralogy, and its uptake by ryegrass grown in pots, has now been completed. The final stage of the work consisted of a rigorous comparison of

electro-ultrafiltration (EUF) with physico-chemical parameters and conventional test methods for soil K. Potassium desorbed by EUF during the first 10 minutes of extraction (K_{10}) was closely correlated with the equilibrium activity ratio for potassium (AR_0) for soils of the same series, but differences between series reflected the soil K buffer capacity, showing that K_{10} includes loosely held exchangeable K and is not strictly an intensity measurement. For 36 soils taken from 3 contrasting soil series neither quantity-intensity (Q-I) nor EUF measurements correlated with K uptake by ryegrass as closely as K exchangeable to ammonium acetate.

Correlation coefficients between K uptake at the first cut and a number of soil K measurements were as follows: 0·80 for K_{10}, 0·88 for K_a (initially labile K derived from the Q-I curve), 0·92 for K_{35} (desorbed by EUF in 35 minutes) and 0·97 for K_{ex} (exchangeable to 1·0M ammonium acetate solution). A paper describing this work has been accepted for publication[6]. 611

A pot experiment started in 1980 to assess the value of adularia shale from N.W. Scotland as a source of potassium to plants, showed no increase in dry matter yield of grass after two cuts following application of up to 30 g adularia to each pot containing 5 kg soil of low K status. The adularia shale contained 6·4% MgO from dolomitic limestone present as an impurity, which raised the Mg content of the grass by 0·15% at the highest rate of addition. In 1981, a similar experiment used a different sample of adularia containing more K and less Mg. The high rate of adularia almost doubled the grass dry matter yield after 4 cuts, compared to no potassium addition, but potassium in KCl was about 40 times more effective than adularia for a given weight of K. Two simple field trials, one on peat and the other on a mineral soil, are being done to assess the value of adularia as a practical fertilizer material. The work on magnesium availability, described in last year's report has now been published[7]. 608, 611

Acid Soil Chemistry. The paper describing interactions between phosphate and aluminium in the response of barley to soil acidity has appeared[8], and experiments extending this work to a wider range of soils are nearing completion. 604

The ability of the soluble polycarboxylic acids[9] found in acid soils to complex copper and aluminium has been studied using potentiometric titrations. The theory and the methodology have been validated in the polycarboxylate-Cu^{2+} system, where a Cu^{2+} ion selective electrode was used for direct measurements of uncomplexed copper. The measured formation constants agreed closely with those calculated from pH measurements alone, so that the pH method could be applied with some confidence to complexes with aluminium, where there is no analytical technique for measuring uncomplexed Al. Formation constants between Al and both natural polycarboxylates and simple mono- and di-carboxylic acids were measured. The results have enabled the proportions of free and complexed Al and Cu to be calculated in soil solutions, given the amount of soluble polycarboxylic acid present[10]. 604

Detailed analyses of profile samples from differentially acidified plots of a field experiment have been made, in order to calculate the rate of acidity development, and hence the need for lime, under different fertilizer regimes in our cool, moist climate. The results are awaiting evaluation and the necessary theoretical treatment. 604

Work described in the 50th Annual Report on the stability constants of copper-polymaleic acid complexes determined by polarographic techniques, has now been published[11]. 614

Sulphur. Publications on work reported previously, comparing different methods for estimating the sulphur status of soils[12], and for determining S-containing amino acids in soils[13], have now appeared.

Work has continued on the significance of low soil sulphur levels for the growth, chemical composition and protein quality of cereal and forage crops, as measured in pot experiments. When phosphate-extractable sulphate levels in soils are less than 10 mgS/kg, responses to added S are always obtained in pots, when other nutrients are adequate. The most sensitive criterion for the S status of a forage crop appears to be its tissue sulphate content, and values in excess of 400mgS/kg dry matter are indications of adequate sulphur nutrition.

Although phosphate-extractable sulphate levels in soils appear to be decreasing, this does not necessarily produce a response to added sulphur in the field, because of the inputs from the atmosphere, from rain, and from the mineralization of sulphur from soil organic matter. Sulphur dioxide in the atmosphere measured at two sites was less than $3\mu g/m^3$, but sulphur in rainfall at the same sites supplied the equivalent of 8-12 kgS/ha per year, *i.e.* at least half of a cereal crop's supply if the S had been stored in the soil. Pot experiments using the ^{35}S isotope are in progress to try to estimate the S supply from mineralization. 601, 602

Molybdenum. The work on the differential pulse polarographic determination of extractable molybdenum in soils, mentioned in the last annual report, has been submitted for publication[14]. A paper describing the wider application of polarographic and voltammetric methods for nutrient determinations in soils has been presented at a conference[15].

An investigation has begun into the effects of pH, soil organic matter content and soil phosphate level on molybdenum solubility, using soils from a long term lime-phosphate field experiment under grass at Craigiebuckler. Samples from 2, 15 and 40 cm depth from various plots were ground to pass a 100 mesh sieve and extracted with 1·0M ammonium acetate and 0·02M potassium nitrate solutions. In all cases the potassium nitrate-extractable Mo values failed to exceed the reagent blank. Ammonium acetate extractable Mo decreased with depth. The most significant feature so far is perhaps the wide variability of extractable Mo in replicate samples of the more highly organic 2 cm samples; this appears to be linked with sampling error, and may indicate that the extractable Mo is heterogeneously distributed in a concentrated form. 614

Piezoelectric Crystal Gas Monitors. Research on these analytical devices has been in progress over the past four years. Ammonia and sulphur dioxide are the two gases being studied. Ammonia may be detected using a silver nitrate coated crystal, and sulphur dioxide with a triethanolamine coated crystal. For both systems, the effects of temperature, humidity and the presence of other gases is being rigorously investigated, and when this is completed it is hoped to develop the detectors as simple field-based monitors. Interim progress on this research has been reported[16]. 614

Selenium. Pot experiments on the uptake by perennial ryegrass of selenite added to a range of soils are continuing. The first year's results show good correlation between Se uptake and the Se-adsorption properties of the soils. The residual radioactivity of the previous ^{75}Se-labelled selenite has decayed sufficiently to allow a further determination of Se uptake by adding freshly-labelled selenite to the same soils. Ryegrass is also being grown in acid-washed sand with added selenite radioactively-labelled with ^{75}Se, to provide internally-labelled radioactive ryegrass standards to check on the accuracy of the plant analytical techniques for Se. 614

Soil and herbage samples are being collected from fields and analysed to see whether the same relationship holds between the uptake of native Se and Se-adsorption, as was found for added selenite. Several instances have occurred where severely Se-deficient herbage has been found on soils with high total Se (>1 mg/kg), and these soils were found to adsorb selenite strongly. When sufficient data have been collected, it should be possible to predict soils with a potential Se deficiency problem. 614

Development and Advisory Work

The reprinting of the Bulletin on Fertilizer Recommendations, prepared jointly by staff of the North of Scotland College of Agriculture and the Macaulay Institute, provided an opportunity to make some minor alterations and additions[17].

Trace Elements. The 1st Study Conference of the Scottish Agricultural Colleges on Trace Elements in the Diets of Farm Animals, recommended the appointment of a small group of staff from the Scottish Agricultural Colleges and Research Institutes to produce an authoritative document on trace element deficiencies and excesses. Dr J. W. S. Reith represented the Macaulay Institute on this COSAC/SARI Trace Element Study Group which met on six occasions during the year. Papers were prepared for the group on the Co, Cu and Mo Status of Scottish Soils, based on data for advisory soil samples from all three College regions for the past ten years; and on Trace Elements in Scottish Soils and Uptake by Crops, especially Herbage. The latter briefly summarizes the main conclusions from field and laboratory studies on grassland herbage during the past 25 years. Based on existing knowledge, the total trace element contents in samples of subsoil B horizons, collected by the Soil Survey Department, are being used to produce a preliminary assessment of Soil Series where the risk of Co and Cu deficiencies or of Mo excess are high, moderate or low. 609, 201

Phosphorus. Annual Report No. 48 (1977-78) summarized relationships between methods of estimating available soil P and the need for P by crops. During the current year ammonium lactate plus acetic acid was also used and the correlation coefficients were generally better than those with acetic acid and ammonium acetate plus acetic acid (Morgan's reagent), although still inferior to those determined by anion exchange resin. The ammonium lactate plus acetic acid method is being evaluated further, in collaboration with the Department of Statistics, to determine if it would be suitable for assessing the P, K and Mg status of soils throughout Scotland. 601, 610, 5701

Since Calcined Senegal Phosphate is now available comercially, further field experiments have been undertaken to compare its effectiveness in soils of varying degrees of acidity. On the basis of existing information a summary of the effectiveness of different types of phosphatic fertilizers was prepared for the staff of The North of Scotland College of Agriculture. 601, 608, 5701, 5703

Advisory Analyses. Over 7700 samples were submitted by the North of Scotland College of Agriculture for the determination of their lime, phosphorus, potassium and magnesium status, of which 130 came from horticultural land. Most samples now have an Ordnance Survey map grid reference, as requested by the Institute, so that the analytical results can be related to the kind of soil derived from Soil Survey maps. The combined information is now being transferred to the Institute's soil data bank. There has been a marked drop in the use of lime in recent years, and a smaller decrease in the used of phosphate. But advisory samples analysed in 1980-81, did not show any marked increase in acidity compared with 1970-74, nor any obvious decrease in the P status, although there was a general reduction in the K status of soils. However, results from advisory samples are likely to be biased towards farms with better management. 608, 610, 5206

Nearly 450 of the advisory soil samples were analysed for trace elements, mainly Co and Cu, but also a number for Mo and Mn. About 40 samples of crops and herbage were analysed for trace elements in relation to poor crop growth or animal problems. Grampian Regional Council submitted 14 samples of sewage sludge which were analysed for both major nutrients and trace elements. As in previous years most of the trace element determinations were done in the Department of Spectrochemistry. 610, 609, 5205

During the year 233 soil samples, mainly from forest nurseries were analysed to assess their lime and nutrient status in collaboration with the Department of Peat and Forest Soils. 608, 117, 5206

As in previous years information on soil, lime, nutrients and fertilizers was supplied to numerous organizations and individuals following both written and verbal enquiries. 608, 609

Work on trends in the nutrient status of soils as revealed by advisory analyses over the years, as described in last year's report, has now been published[18]. 608

Radioisotope Unit

Apart from the continued involvement in a number of research projects in the Institute, the unit has wholly organized the XIIth Annual Meeting of the European Society of Nuclear Methods in Agriculture (ESNA), held in Aberdeen from 28 September to 2 October, 1981. This is the first time that ESNA has met in the United Kingdom. The meeting provided a unique opportunity to meet agriculturalists using nuclear methods from every country in Europe, and for the staff of the Institute to describe some of their research in the paper-reading and poster sessions.

613, 5613, 304, 305, 309, 311, 407, 512, 601, 614

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8. STATISTICS

R. H. E. INKSON

The Department continues to provide collaboration to colleagues throughout the Institute with specialized advice and services in the application of statistical methods. One of the main subject areas covered is the planning of experiments, with the choice of the appropriate design and the consequent method of statistical analysis, for research in the field, forest, glasshouse and laboratory. In addition to the analysis of variance of sets of observations from designed experiments, other methods of statistical analysis such as multivariate techniques and model-building are applied to the results of sample surveys and the accumulated records of series of experiments. The Department also provides specialized services in data processing, computer operation and programming.

Members of staff attended meetings of the Royal Statistical Society, the ARS Computer Users' Group, the ARS Group for Users of Small Computers, the SARI/SAC Micro Club, and computer and microprocessor exhibitions and demonstrations.

Computing

The Department provides the central computing facilities for the Institute and has the responsibility for managing and operating the system and for providing the essential programming support and data entry service. The core memory of the Eclipse C/150 has been increased to 768 Kbytes, and a second disk subsystem of 192 Mbytes and a Tektronix graphics display terminal have been installed. An Apple II microcomputer has also been interfaced to the Eclipse.

The departure of Dr D. A. P. McKay has delayed progress with the Institute's main soil information system. However, Mr K. W. M. Brown has joined the Department and will be responsible for database activities. A successful training course on the use of computer terminals was arranged for members of the Department of Soil Survey. Further courses have been planned for new and intending users of the Eclipse computer.

Further facilities have been added to Data General's INFOS file management system by the purchase of Query and Report Writer software for selecting, displaying and printing database records in the form of a report. Statistical programs for a range of multivariate methods, for non-linear regression and for screening input data for analysis of variance programs have been amended for the Eclipse by Mr A. W. Wilson while on secondment from Robert Gordon's Institute of Technology. The screening pro-

gram provides a means of indicating whether a transformation of the data may be necessary to permit a valid analysis and tests of significance. 703

Further statistical programs have been converted to run on the Eclipse as the need for them arose. These are for Latin Squares (LATIN), balanced lattice squares with prime side (LSOD2), covariance in factorial designs (FCV), Latin square with an additional row (LATXR), missing value estimation in central composite designs (CCMV), and split-plot designs (SPAVA). 703

Most programs previously converted have been updated, when suitable opportunities occurred, to improve efficiency on the Eclipse system. For example, the compare and combine sections of the regression program FRECO were rewritten to make the interactive options easier to use from a terminal as opposed to the selection of switches on the IBM 1130 console. 703

A new subroutine has been written to examine components of interactions between two factors which both require multiple range tests. It has been incorporated into a factorial analysis of variance program LEGACY, adapted from the five-factor program FF. Limitations on both core space and programming time made this two program choice preferable to inclusion of additional options in FF itself. A new program (EADAR) for the general analysis of variance of the one-way classification structure has been written. It allows for a higher number of observations per class than the use of FF for one factor, and for classes with differing numbers of observations. 703

Peat and Forest Soils. Modifications have been made to the program which uses rectangular homogeneous training areas to produce histograms of reflectance frequencies as an aid to the selection criteria for classifications of LANDSAT data. A further program prints LANDSAT scenes using the Data General line printer as a plotter. Such maps or their numerical representations are now provided as a regular service. A joint account of an earlier stage of this work[1] has been published. 119, 703, 5703

Spectrochemistry. There is now a regular service for data input from punched paper tape, for plotting spectra and for graphical output from data in hexadecimal format relating to convoluted integrals. 201, 203, 205, 206, 703, 5703

Soil Organic Chemistry. Data entry, verification and editing have been completed for a podzol chronosequence study covering a range of chemical properties of the horizons in 173 soil profiles. 304, 5703

Soil Fertility. Data from magnetic tape cartridges have been read into the Eclipse via a Microdata data logger. A regular service has also been provided to read data from tape cassettes using a Commodore PET as the input device for the Eclipse. In this way a data bank is being built up for the soil advisory service. A program has already been written to extract specific information from the data bank. 608, 703, 5703

Soil Survey. All Soil Inventory profile descriptions received have been entered from the field record cards, verified and processed using the INFOS file management system to present the coded information in plain text. A joint account[2] of the use of the recording form and the processing programs has been submitted for publication. A data base has been established for the plant phytosociological data from vegetation surveys and a regular service of data entry and verification provided. 801, 802, 703, 5703

Advisory and Collaborative Work

Mineral Soils. Several methods of multivariate analysis have been used to discriminate between different types of soil and using different horizons in soil profiles. 108, 701, 703, 5703

Peat and Forest Soils. Whole tree sampling for the sixth in the series of central composite design experiments on Sitka spruce has provided considerable quantities of data for processing and statistical analysis. The data entry and checking programs for this project were modified to allow for changes in sampling procedure and age of trees. After initial processing to produce dry weights, further program conversions (from IBM 1130 to D.G. Eclipse) were made to take the data from this experiment and the previous one through the next stages:— calculation of log/log regressions on basal area for different tree parts, solution of those regressions for appropriate stem size distributions and calculation of needle area. The data are now ready for input to foliage profile programs, but these programs require some amendments to be made before they can be used on the Eclipse. Ring width data from the same two experiments have been processed and analysed. 115, 703, 5701, 5703

Rainfall data from Sitka spruce experiments for further years have been processed as described in the 50th Annual Report. The remaining programs have been converted and the data processed through the later stages, namely the calculation of the elements in rainfall in kg/ha (UISGA) and period totals (UISGP), and the extraction of data for mm rain and kg/ha of elements to plot against time (UISGX and UISGZ). Previously pH values had been ignored, but two new programs have been written to extract (UISGH) and process (UISGK) this data to obtain amounts of H in kg/ha, and this was done for all years in four experiments in the series. This completes the processing of five years' data from each experiment. Combined five-year graphs of mm rain and kg/ha of elements against time have been plotted for three of these experiments. 115, 703, 5701, 5703

An investigation of acid rainfall in Glentanar (supported by CEGB) has provided data for processing by new programs written to convert volumes to mm rain and ppm chemical data to milliequivalents and kg/ha. The data were collected for six different species from up to eight different catchment categories, and so analysis of variance was done by the new factorial program with range tests on interaction components (LEGACY). Graphs of mm rain and kg/ha of elements against time have been plotted using UISGZ. Work is continuing on this project. 115, 703, 5701, 5703

Routine processing of the results of chemical analysis continues. Correlation and analysis of variance have been used in experiments on the growth of sphagnum shoots, nitrogen mineralization in peat from a controlled water table experiment, for basal area increment data from Culbin experiments, and in relating pupal counts of the Pine Beauty Moth to various chemical components of trees. Collaborative work on biomass and accumulated nutrients in Corsican pine has resulted in the publication of a set of tables[3], and a joint account of work[4] on the nitrogen content of pine needles has been accepted for publication.

110, 112, 115, 116, 117, 5701, 5703

Spectrochemistry. Regression equations have been estimated from data concerning band spectra. 205, 5701

Soil Organic Chemistry. In the analysis of variance of a factorial experiment on oats, the copper content at different stages of growth required logarithmic transformation. A joint account of other work[5] on the amino acid composition of the oat plants has been accepted for publication.

307, 401, 5701, 5703

Plant Physiology. Experiments of factorial and randomized block design have been used in studying the growth rate, chemical composition and ultrastructure of Lemna fronds. The effects of a range of factors have been tested and the main emphasis has been on selenium. Work has also continued on the testing of the significance of the differences in the chemical composition of Brussels sprouts samples. A joint account of work[6] on cavity spot in carrots in which the angular transformation was used has been accepted for publication. Factorial and randomized block designs have been used in tomato experiments. The factors tested were moisture regime, source of nitrogen supply and truss size. Joint accounts of this work[7, 8] have been accepted for publication. 402, 407, 5701, 5703

Microbiology. The program for estimating microbial numbers with confidence limits from dilution series data has been used for a number of experiments. The use of square root and logarithmic transformations has been investigated on Utermohl count data. Further work has been done on counts of anaerobic bacteria at regular depth intervals in a deep basin peat. Regression relationships between heat output, respiration and biomass have been estimated for four groups of soil. Tests of significance between slopes and intercepts have been made and soil groups combined where possible.

503, 510, 512, 513, 701, 5701, 5703

Soil Fertility. The range of experimental designs used in the field experiment program extends from randomized blocks to lattice squares and central composite designs. 601, 603, 606, 607, 608, 609, 612, 701, 5701

Work continues on the use of regression equations that relate crop response to added phosphate fertilizer to various laboratory measurements of soil phosphorus. Analysis of variance and regression methods, in the study of the pattern of plant growth and development of barley, swede and potato crops, were applied to data on physical and chemical properties of

the plants and on growth rates. Correlations have been obtained between chemical properties for many plant species and different plant parts, and between C.E.C., latitude and volume production of timber for Lodgepole pine. Analysis of variance and regression methods have been used for pot experiments on oats and ryegrass, and in relating yield and potassium uptake in ryegrass to a range of soil K values for three soil series. Tests of significance of differences between slopes and intercepts were made.

601, 603, 607, 611, 613, 5701, 5703

A joint account[9] of work on the regression relationships between porosity and water tension has been accepted for publication.

612, 5701, 5703

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9. SOIL SURVEY

R. GRANT

The survey at 1:250 000 has again dominated the year's work with the mapping of the Outer Isles, 2876 km², during April/May by a team of four surveyors completing the field programme. Relevant legends have been compiled and maps with scribed soil boundaries submitted to Ordnance Survey where work is on schedule for production of colour proofs of all seven sheets by the end of the year. Work is nearing completion for the matching land capability for agriculture (LCA) maps with final consultation meetings in hand. A revised classification for land capability assessment has been prepared for publication with improved guidelines and provision for subdivision of classes. A start has been made on writing the descriptive handbooks to accompany the 1:250 000 maps. Progress has continued with the collection of profile descriptions and samples for analysis for the National Soil Inventory. Summary accounts of the soils of the individual sheet areas are given below.

With the completion and publication of the soil and land capability maps covering the Orkney Isles the Survey office in Kirkwall has been closed and the surveyor-in-charge transferred to Edinburgh to re-establish the Survey Regional Office at the Edinburgh School of Agriculture. The Survey has moved to a new office in Oban, in premises shared by DAFS and MAFF officials; this move has already resulted in an increase in consultation and improved liaison.

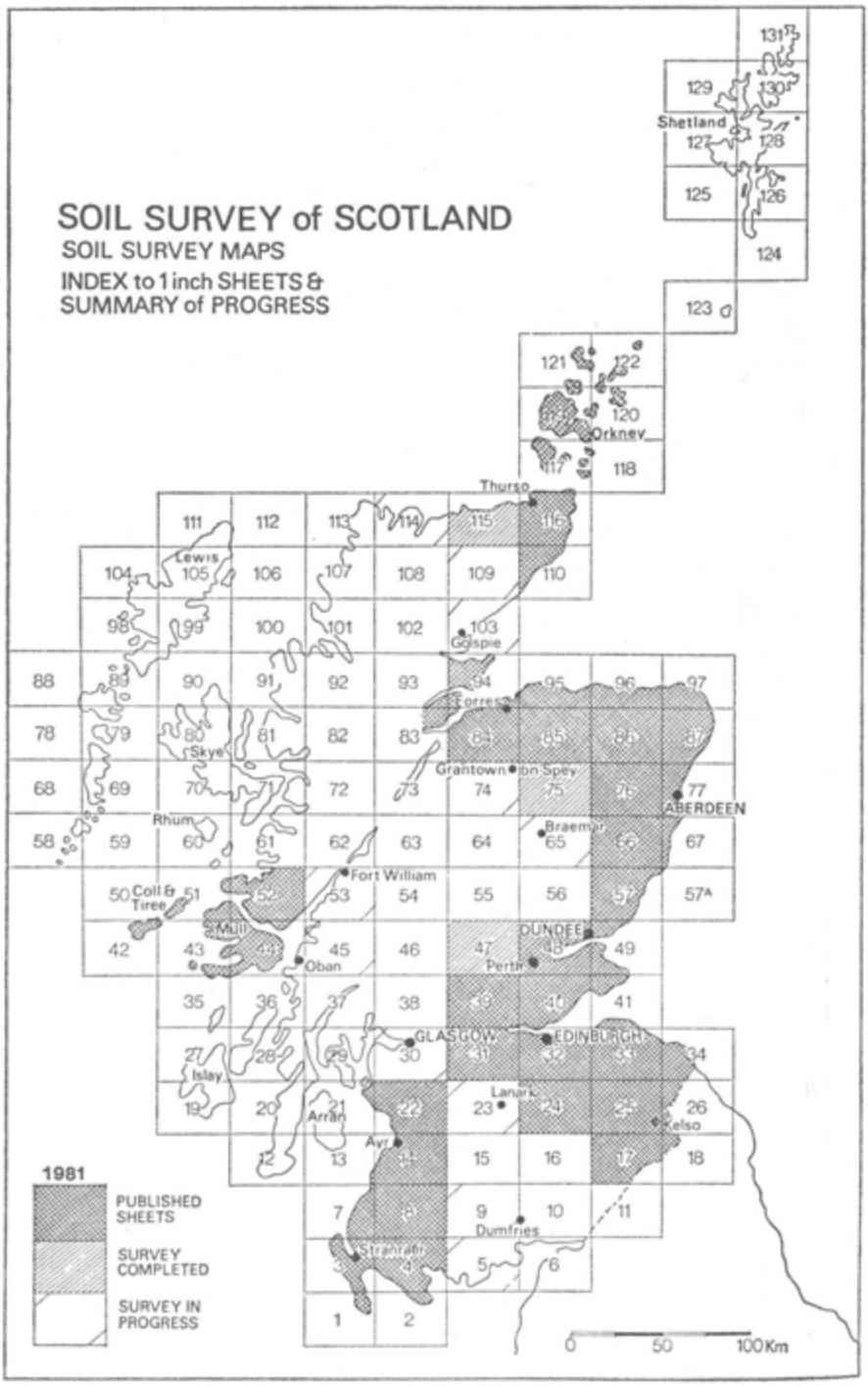
The demand for soils information continues unabated, from a wide range of users and for a variety of purposes. Every effort has been made to comply with such requests.

The Soil Survey has been represented on the MAFF/ADAS/Soil Survey Working Party on Land Capability, the DAFS Working Party on Hill Land Classification, the Scottish Development Department Working Party on Rural Land Use Information Systems, the DAFS Field Drainage Group and the Euro-Carto I Group which is preparing a seminar on Digital Cartography in Europe: Vegetation Mapping, other soil and vegetation maps, produced by the Institute and scan-digitised by computer to demonstrate the value of an Eco-topography data base, will be the basis for discussion.

801, 802, 804

Sheet 1 (Orkney and Shetland)

The 1:250 000 mapping programme of the soils and land capability of Sheet 1 is now complete and a preliminary summary may be presented. Sheet 1 encompasses north-east Caithness, Orkney and Shetland, a total land


SOIL SURVEY of SCOTLAND
SOIL SURVEY MAPS
INDEX to 1 inch SHEETS &
SUMMARY of PROGRESS
Shetland
Orkney
Thurso
Lewis
Golspie
Forres
Skye
Grantown on Spey
ABERDEEN
Rhum
Braemar
Fort William
Coll & Tiree
Mull
DUNDEE
Oban
Perth
GLASGOW
EDINBURGH
Islay
Lanark
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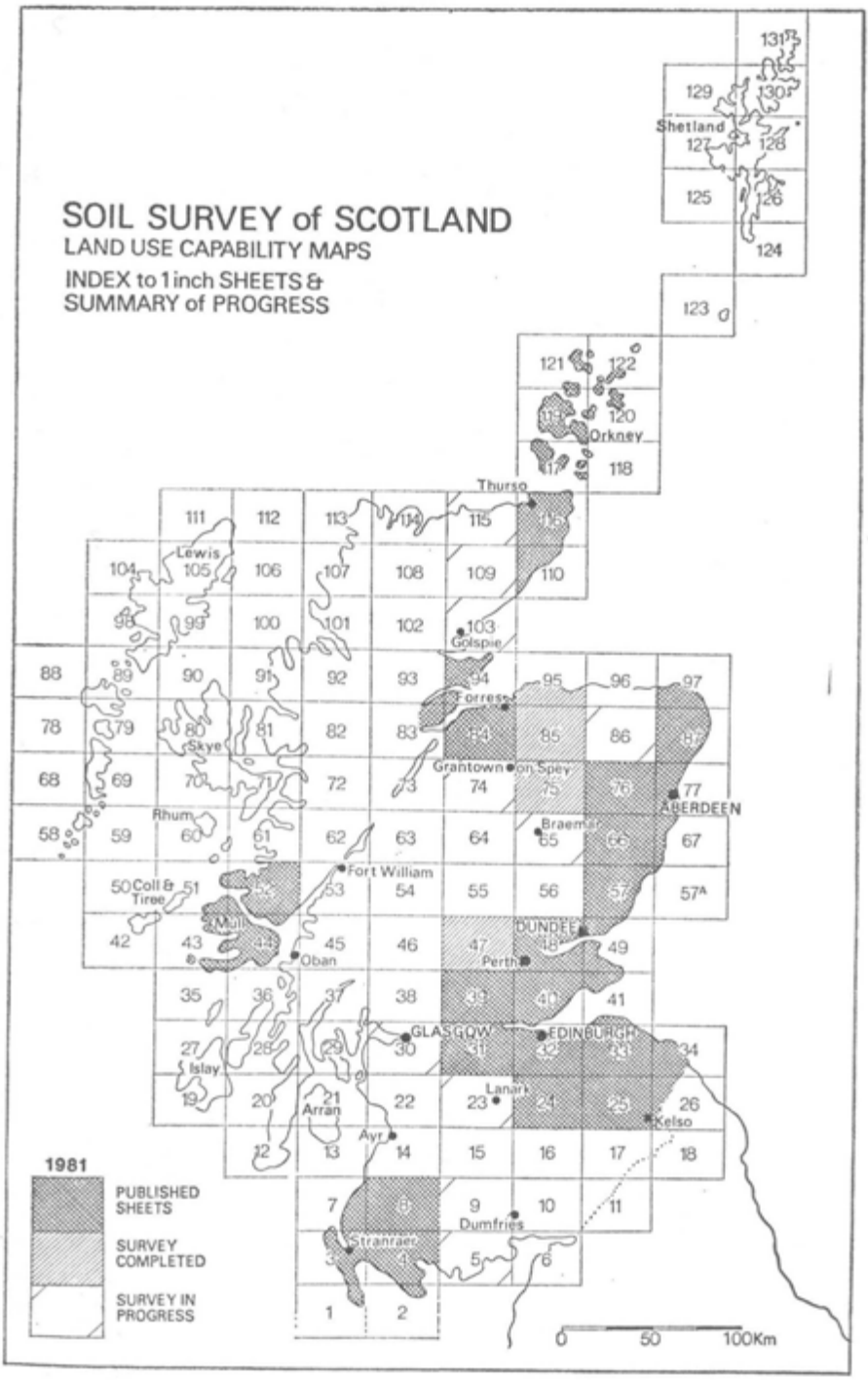
SOIL SURVEY of SCOTLAND
LAND USE CAPABILITY MAPS
INDEX to 1 inch SHEETS &
SUMMARY of PROGRESS
Shetland
Orkney
Thurso
Lewis
Golspie
Forres
Skye
Grantown on Spey
ABERDEEN
Rhum
Braemar
Fort William
Coll & Tiree
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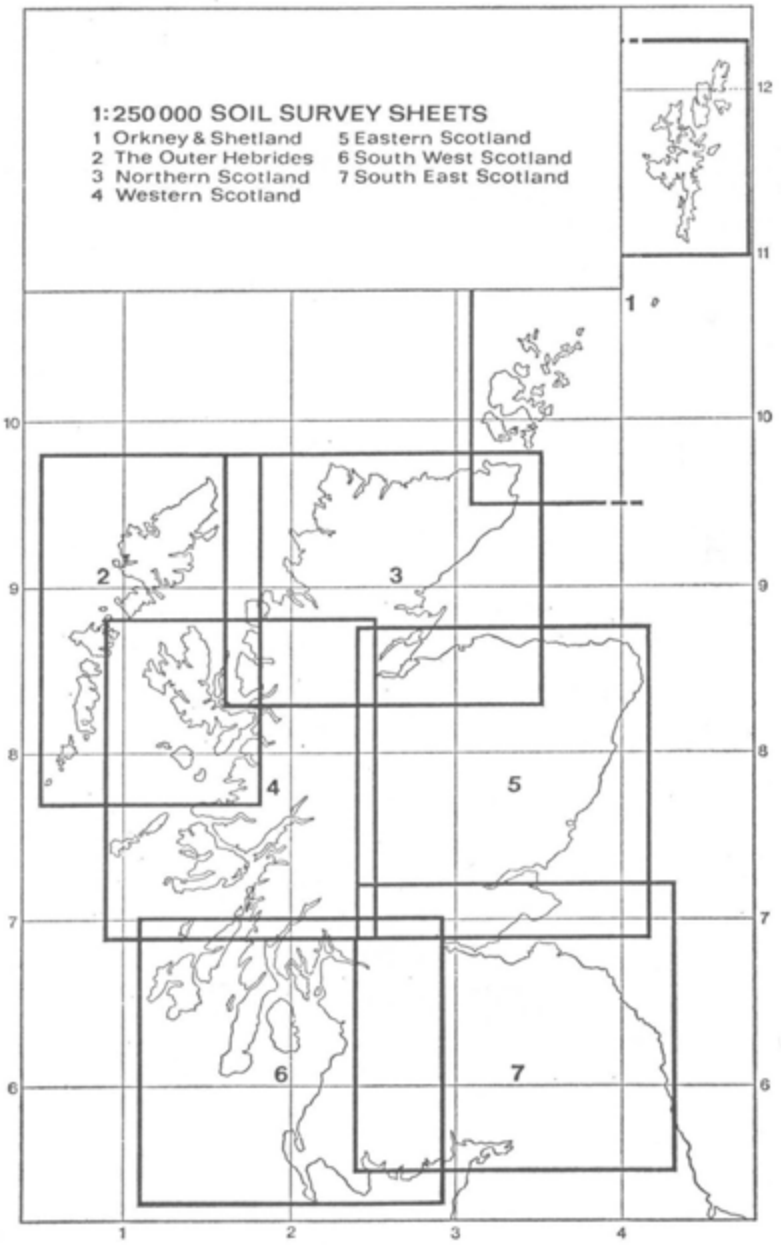
1:250 000 SOIL SURVEY SHEETS
1 Orkney & Shetland
2 The Outer Hebrides
3 Northern Scotland
4 Western Scotland
5 Eastern Scotland
6 South West Scotland
7 South East Scotland
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area of 3014 km². The area offers a broad spectrum of soils and landforms and is perhaps best considered in terms of two major landform regions, north-east Caithness and Orkney, and Shetland.

North-East Caithness and Orkney

The solid geology of the region is relatively uncomplicated, the area consisting almost entirely of gently inclined sedimentary rocks and subordinate lavas and tuffs of Middle and Upper Old Red Sandstone age. The geological succession is dominated by flagstones — rhythmic sequences of thinly bedded and, in part, laminated grey and black carbonate-rich siltstones and silty mudstones alternating with generally thin beds of sandstones. The landscape is usually gently undulating and of subdued relief. The climate of the region is cool and equable. The average rainfall of approximately 900 millimetres is fairly evenly distributed throughout the year. The annual range of mean monthly temperature is around 9°C, increasing from about 3·5°C in February to about 12·5°C in August. Although winter temperatures are not very low, there is only a slow build-up of temperature and winter and spring tend to be rather prolonged. Perhaps the most significant element of the climate is the high incidence of strong and gale force winds. The superficial deposits of the area are mainly the various drift deposits associated with the Pleistocene Glaciation. Two main types of till occur (i) a compact brown or greyish brown medium- to moderately fine-textured till derived from rocks of the Middle Old Red Sandstone, such material giving rise to soils of the Thurso Association, (ii) a compact reddish brown moderately fine-textured till derived from rocks of the Middle Old Red Sandstone, the material of the Canisbay Association. The mineral soils of the region have been mapped within two major soil complexes. The first complex is dominated by soils of the Thurso series (noncalcareous gley of the Thurso Association) with subsidiary Bilbster series (brown forest soil). The complex occupies approximately 25 per cent of the region (13% of Sheet 1) and occurs on a non-rocky gently undulating and largely cultivated landscape. The second complex is similarly dominated by noncalcareous gleys and occupies a similar landscape, but here the soils are of the Canisbay Association, the dominant soil being Tresdale series. This complex accounts for approximately 14 per cent of the region (7·5% of Sheet 1). A complex of the Thurso Association dominated by soils of the Bilbster series with subsidiary Thurso series, occurs on a more strongly sloping landscape and occupies some 12 per cent of the area (6·5% of Sheet 1). Peat is extensively developed, covering some 20 per cent of the region.

The land capability of the region is profoundly influenced by climate and particularly by exposure. The rigours of climate determine that no soil can be in a better class than 3. The Class 3 land is of limited extent and confined totally to north-east Caithness. With increase in exposure as in Orkney, or as in Caithness where the increase is closely allied to increased elevation, no soil can be better than Class 4. Classes 5 and 6 occur extensively.

Shetland

If the solid geology of north-east Caithness and Orkney is relatively uncomplicated then that of Shetland is undoubtedly complex. Shetland consists partly of ancient sedimentary rocks which were metamorphosed and intruded by igneous rocks during the Caledonian orogeny and partly by sedimentary and volcanic rocks of Old Red Sandstone age. The complexity of the geology is illustrated by the range of rocks encountered, schist and gneiss, phyllitic schist, quartzite, crystalline limestone, serpentinite, metagabbro, granite, rhyolite, conglomerate and sandstones. It is also shown by the mapping of the parent materials of as many as twelve soil associations. The landscape is equally variable with rugged, strongly undulating, rocky lowland and foothills, steep rocky slopes, steep non-rocky slopes, undulating lowland and foothills with gentle to strong slopes, stony plateau summits and narrow valley sides. In spite of its latitude the area does not suffer too severe a climate, the climatic effects of such a latitude being ameliorated by the North Atlantic Drift. The temperature regime is marginally cooler than that of north-east Caithness and Orkney, the annual range of mean monthly temperature being around 9°C, increasing from approximately 3°C in February to 12°C in August. Rainfall generally exceeds 1100 millimetres. There is no doubt that the most significant climatic element is the overall windiness and very high incidence of strong to gale force winds.

The Shetland landscape is dominated by peat. Approximately 40 per cent of the area has been mapped as peat with most of the peat exceeding 100 centimetres in thickness. The peat occurs on slopes ranging from gentle to strong and occasionally steep and much of it is eroded to a greater or lesser extent. The mineral soils of the region have been mapped in five principal soil associations (i) soils of the Arkaig Association developed on coarse and moderately coarse-textured drifts derived from acid schists and gneiss of Moinian type (approximately 22% of the area), (ii) soils of the Countesswells Association developed on coarse- and moderately coarse-textured drifts derived from granite and allied rocks (approximately 11% of the area), (iii) soils of the Walls Association developed on moderately coarse-textured drifts derived from sandstones of the Middle Old Red Sandstone with some acid schists (approximately 7% of the area), (iv) soils of the Leslie Association developed on medium- to moderately fine-textured drift derived from sepentine (approximately 4% of the area), (v) soils of the Skelberry Association developed on medium- to moderately fine-textured drift derived from sandstones, flagstones and conglomerate of the Middle and/or Upper Old Red Sandstone with some phyllitic schists (approximately 4% of the area). Six soil complexes have been determined within the Arkaig Association. The dominant complex comprises peat, peaty gley, peaty podzols and peaty rankers developed on a strongly undulating, rocky landscape. The complex accounts for approximately 8·5 per cent of the region (4·0% of Sheet 1). A further complex with a similar landform, but essentially lacking peat, has also been mapped over some 4·5 per cent of the area. Complexes of noncalcareous gleys, peaty gleys with peaty podzols

and some peat have been mapped on gentle to strong slopes over some 4·0 per cent of the region. Four soil complexes were mapped within the Countesswells Association. The principal complex accounts for some 6·0 per cent of the region (2·8% of Sheet 1) and comprises peat, peaty gleys, peaty podzols and peaty rankers developed on a strongly undulating, rugged, rocky landscape. A complex of peaty podzols, brown forest soils with some noncalcareous gleys was mapped on gentle to strong, generally non-rocky, slopes. This complex comprises approximately 2·7 per cent of the region. A small (approximately 1%) complex of alpine soils was encountered on Ronas Hill.

The dominant complex of the Walls Association covers approximately 2 per cent of the area and comprises peaty gleys, peaty rankers with some peaty podzols and peat developed on an undulating rocky landscape. A complex of similar landscape yet dominated by peat with peaty gleys, peaty podzols and peaty rankers occupies a further 1·5 per cent of the region. A third complex (approximately 1·5% of the area) dominated by ranker soils occurs on a strongly undulating, very rocky, rugged landscape and on very steep ridged hills.

The soils of the Leslie and Skelberry Associations have each been mapped into three complexes on the basis of degree of slope and rockiness.

Arable land is undoubtedly at a premium in Shetland being largely confined to the coastal fringes, to those areas where the proximity of shelly sand has offered some ameliorative agency, to those soils influenced by crystalline limestone and to the unique soils of the Leslie Association. No soil can be in a higher class than 4. Classes 5, 6 and 7 have been recognised with Class 6 being the most extensive and dominating the landscape.

Sheet 2 (The Outer Hebrides)

The land area on the sheet is 5561 km², divided into three main physiographic regions. The Outer Hebrides comprise 2876 km² (52%), the Northern Inner Hebrides 1894 km² (34%) and the Mainland area 791 km² (14%). Slightly to very rocky moorland dominates the area, with uplands and mountains on Skye, Rhum and the Mainland. Low-lying crofting and farm land occurs on the machairs and at the mouths of large valleys.

The soils are related to rock type, structure and reaction to soil forming factors. Soil parent materials and rock types which contribute to them are as follows:

Recent	— Peat, alluvium and saltings.
Post-glacial	— Raised beaches and machairs.
Pleistocene	— Fluvioglacial deposits, moraines and tills.
Tertiary	— Intrusive: Ultrabasic rocks, eucrites, gabbros, felsites, granophyres and granites.
	— Extrusive: Basalt and mugearite.
Mesozoic	— Cretaceous sandstones, Jurassic sandstones and clays, Permian and Triassic sandstones.
Palaeozoic	— Durness limestone and Cambrian quartzite.
Torridonian	— Arkoses, sandstones and mudstones.
Moinian	— Psammitic granulites and pelitic schists.
Lewisian	— Gneissose granites, metasediments, paragneisses and orthogneisses.

A number of glacial episodes have formed the till, moraine and outwash in this area. Periglacial processes have resulted in large areas of colluvial drift and scree, and a combination of agencies has produced the machair. The main area of till is on Lewis, north of a line between Stornoway and Shawbost, while smaller areas are found on Skye. The Lewis till plain is covered by a blanket of peat, while mineral soils occupy a narrow coastal fringe. This till is mainly derived from Lewisian rocks and their pre-glacial weathering products, but a small area of reddish-brown till in the Stornoway area is derived from Triassic conglomerates. Clayey tills derived from Jurassic rocks are found at the Butt of Lewis and on north Skye.

Moraines occur in mountain glens in all regions of the sheet and are deposits of readvance glaciation. The Uists and Benbecula have substantial areas of moraines deposited on low-lying ground with no adjacent high ground. This deposit is usually derived from the underlying rocks.

Outwash and raised beach areas have been divided into those dominantly derived from acid rocks, and basic or ultrabasic rocks.

The climate of the area is a result of travelling depressions moving from the south-west, and interspersed anticyclones of variable duration. The main components of the weather, rainfall and temperature are summarised on the map of the Bioclimatic Sub-Regions of Scotland. The hyper-oceanic sub-sector influences much of the area, and the main thermal sub-zones are boreal with arctic on the mountains, but small areas of northern temperate occur around the Sound of Arisaig, Plockton, Broadford, Loch-boisdale and Barra. Moisture sub-divisions reflect the rainfall which ranges from around 1200 mm along the Outer Hebridean coast to over 3400 mm on the mountains.

The map has 98 mapping units and they are grouped into 22 soil associations. Many of these are described in the sheet 4 account, so only four of the associations are discussed here.

The most extensive association is Lochinver which covers 2081 km², or 37% of the land area of the sheet. Peat-covered ground and areas with peaty soils form most of the area, but mineral soils are found on rocks of Lewisian age which are close to the Moine Thrust where it crosses the Sleat peninsula on Skye. Fourteen map units have been delineated, but some of them cover only small areas.

Map units of peat, peaty gleys and some peaty podzols cover 1302 km² and form much of the Outer Hebridean landscape. There is a range of slopes from level to steep and rockiness varies from slight to extreme. Where rock outcrops are absent, usually because of an increase in peat depth, a unit dominated by peat with some peaty gleys has been mapped, covering 231 km².

Hummocky moraines in this association occur in two contrasting situations: in the mountain glens of North Harris, and on the lowlands east of the machairs in the Uists and Benbecula. They are often strewn with boulders in the mountainous area, but surface boulders are less dominant in the Uists and Benbecula. Two units have been mapped: a mineral soil

unit and a peaty soil unit occupying 45 km² and 272 km² respectively. The mineral soils are humus-iron podzols on the freely-drained hummocks, with mineral, humic and peaty gleys in the hollows. The soils are stony and have loamy sand or sand textures which result from the coarse-textured parent rock. Crofting and farming are practised on these soils and there are plentiful reserves of adjacent shelly sand for pH control. Peaty moraines have peaty podzols on the better drained hummocks with peat or peaty gleys in the hollows and channels.

The Lochinver Association till of North Lewis occurs from Shawbost on the west around the coast as far as Tolsta. There is a slightly less stony variant of the till occurring in patches around Ness, overlying Lewisian metasediments. There are two soil units, mineral and peaty. The mineral soils are non-calcareous gleys, humic gleys and humus-iron podzols, which are thought to have developed by cultivation of peaty gleys and peaty podzols. Some cultivated peaty soils are included in the unit. The subsoils are compact and would respond well to subsoiling if the appropriate machinery could be made available to the crofters. Peaty areas cover 50 km² and the soils are peats and peaty gleys on gently sloping ground, and peaty podzols with iron pans on slightly steeper slopes. Peat cutting at the fringes of the main peat area has formed this kind of ground between the mineral soils of the crofting townships and the peat plain. Reseeding and cultivation is gradually improving the areas where the organic horizon is thinnest.

The mountain tops and steep upper slopes of Harris and South Uist have alpine and subalpine podzols with gleys and peat in receiving or flushed sites. These areas are separated into plateux and slopes, and gleys, peat and some podzols occur on the gentler slopes while the steeper ground dominantly has podzols. The steep unit covers 55 km² of the sheet while the plateaux and ridge crests occupy 40 km².

The Fraserburgh Association covers 125 km² or 2·25 per cent of the sheet and, with the exception of 1 km² on the mainland, it all occurs on the Outer Hebrides, of which region it forms 4·3 per cent. The parent material of aeolian shelly sand has a variable free calcium carbonate content and is used instead of lime on the surrounding land to correct the acid pH.

Mineral soils usually show very weakly developed profiles, reflecting the unstable, mobile nature of the sand, which is one of the most recent deposits in the area. Units consisting of gently undulating aeolian plains and of strongly undulating sand dunes have been delineated on the map. The soils on the dunes are excessively well-drained rankers with weakly developed shallow A horizons over slightly greyer C horizons. On more level sites, where soil profiles are presumed to have been forming for longer, surface horizons are dark greyish brown or dark brown, with a very, weakly expressed B_h horizon present over a light brownish grey C horizon. The soils are immature brown calcareous soils or calcareous rankers.

Contrasting with the machairs of the Inner Hebrides, which are usually freely drained, there are substantial areas of calcareous ground water gleys on the Uists and Benbecula. These soils are very similar to the immature

brown calcareous soils, but the C horizon is greenish grey or grey because of waterlogging and its associated reduction of iron compounds. There are also horizontal, narrow 1-5 mm bands of humus accumulation deposited at the surface of the water table in the C horizon. These soils are potentially some of the best for agriculture as they are moist enough to resist erosion by wind, yet have moisture reserves to withstand short dry periods. Eutrophic peats and peaty calcareous gleys occur in low-lying (2-10 m above sea-level) hollows between the machairs and adjacent hill slopes.

The Stornoway Beds have formed a till which is the parent material of the Arran Association, also mapped on sheet 6. The soils of this association cover 36 km² and are mapped as two units. The cultivated ground consists of noncalcareous and humic gleys with some humus-iron podzols. The C horizon is reddish brown, contrasting with the greyish or greenish grey colours of the till formed from Lewisian rocks. Peats and peaty gleys occur at the fringes of the Lewis peat plain where peat-cutting has reduced the peat thickness.

Organic soils occur as parts of map units in many of the associations. Areas of peat >50 cm, large enough to map at this scale, cover 867 km². The profiles have a black surface horizon, over a dark reddish brown or brown horizon which turns black on exposure to air. These soils are poorly or very poorly drained.

The moorland vegetation of the Outer Hebrides is dominated by northern elements with *R. lanuginosum* and *Cladonia* spp. Bog heather moors and blanket bogs are the most frequent, with flying bent bog and deer grass bog being less extensive. White bent grasslands occur on steep mountain slopes, maritime grassland is seen at numerous localities on west or south-west facing coasts. Meadow grass-bent grassland and eyebright-red fescue dune pasture form the good grazing on the uncultivated machair. Silverweed pasture develops on peats and peaty gleys at the inland edges of the machair.

The highest Land Capability for Agriculture is Class 4 because of climatic restriction. This land is confined to the mineral till soils, and some more stable areas of machair. Cropping of the land is very restricted and much of the ground is under grass. Class 5 is found on less stable machairs and some areas of peaty ground under lower rainfall, particularly around the mineral soil areas of North Lewis. The main area of the map is Class 6 and this is subdivided into good, moderate and poor relative grazing value. Land with good grazing value is restricted to machairs; moderate grazing land is found in the mountains, but poor grazings dominate the area.

Sheet 3 (Northern Scotland)

This account deals only with the part of Sheet 3 lying to the north and west of the Great Glen, an area of 14 259 km² which includes Caithness, Sutherland, most of Ross-shire and part of Inverness-shire. The part lying to the east — Nairn, part of Moray and part of Banff — is covered in the account for Sheet 5.

The geology consists predominantly of metamorphic rocks of Lewisian

and Moinian age with sedimentary rocks of Torridonian and Cambrian age in the west and Old Red Sandstone in the north-east and around the Moray Firth. Soil parent materials are mostly stony and coarse-textured drifts, although some derived from O.R.S. rocks are loamy. The rainfall ranges from 800 mm at the Moray Firth to more than 2400 mm in the mountains of the west. Most of the area falls into the boreal bioclimatic subregions, with some temperate around the Moray Firth and some arctic in the mountains. Cultivated land occurs mainly in the lowlands of the east and north-east. Much of the land elsewhere is uncultivated, the vegetation consisting of the moorland communities bog heather moor, blanket bog and Atlantic heather moor dominating the lower land and the oroarctic communities mountain azalea — lichen heath, brown bent grass — woolly fringe moss heath and nardus grasslands present on the higher ground.

Peaty gleys, peat and peaty podzols with iron pan are the predominant soils, with humus-iron podzols extensive in the east and noncalcareous gleys common in the north-east. The soil map for this part of Sheet 3 shows 124 soil map units grouped into 26 soil associations including alluvial and organic soils.

The area can be described conveniently in four main regions.

North-West Highlands

This region lies to the west of the Moine Thrust, a major structure line which extends from Loch Carron in the south to Loch Eriboll in the north. The landscape is hilly, rocky, and partly mountainous. The underlying rocks are mainly Lewisian gneisses and Torridonian sandstones and grits, with a narrow band of Cambrian and Lower Ordovician rocks along the line of the Thrust comprising a lower group of quartzites and an upper one of limestones. The Lochinver, Torridon and Durnhill Associations are developed on stony, coarse-textured drifts derived respectively from the gneisses, Torridonian rocks, and quartzites. The main soil map units in all three associations are complexes of peaty gleys, peat and some peaty podzols, mostly on rocky, but also on non-rocky landscapes, and complexes of peaty podzols and peat on hummocky valley moraine. Brown forest soils and humus-iron podzols on steep rocky slopes occur locally on the lower ground, and sub-alpine and alpine soils occur on the rocky and bouldery mountains. The Inchnadamph Association, developed on loamy drifts derived from the limestones, contains two map units — one a complex of rendzinas and brown forest soils, the other a complex of rendzinas, peaty soils and peat.

Most of this region is uncultivated and falls into Land Capability for Agriculture Class 6, the limitations being climate, wetness and slope. The small patches of crofting land around the coast are assessed as Class 4.

Moine Plateau

This region, the most extensive in the area, includes part of Inverness-shire, Central Ross-shire and most of Sutherland. It is lower and undulating in the north, with a few hills standing above the general level, but higher and strongly dissected in the south, with hills up to 1000 m and more.

Moinian rocks — mainly roughly foliated quartz-feldspar granulites with some mica-schists and, more rarely, quartzites — are extensive. Granitic rocks, including pre-foliation granites, injection-complexes with migmatites, and intrusions of Newer Granites age occur sporadically. Also, there are a few small inliers of Lewisian gneiss and one or two small outliers of Old Red Sandstone.

Soils developed on drifts derived from the Moinian granulites and schists now form the Arkaig Association (they were previously included in the Strichen Association, but that name is now confined to soils developed on drifts derived from Dalradian rocks); soils on drifts derived from the granitic rocks belong to the Countesswells Association. In both associations the dominant map units are peaty gleys, peaty podzols and peat on non-rocky gently undulating to hilly land. Other common units are one with a similar range of soils on rocky land, and one with peaty podzols and peat on hummocky moraine.

Units of humus-iron podzols on valley sides in the east of the region, and subalpine and alpine soils on the higher hills occur less frequently. Deep peat is very extensive, particularly in north and central Sutherland, and on higher ground it is usually hagged.

Most of the land is assessed as LCA Class 6, with Class 5, where climate, slope and wetness limitations are less severe. Some Class 4 land occurs in the straths of the east and north.

Moray Firth Lowlands

This region, comprising part of east Sutherland, Easter Ross and part of Inverness-shire, is also formed of Old Red Sandstone rocks. It is predominantly a lowland region but includes hilly land in the western part. The rocks are of Lower, Middle and Upper ORS and comprise red and yellow conglomerates and sandstones with some shales and mudstones. Soil parent materials are mostly reddish and brownish tills of sandy loam, sometimes sandy clay loam, texture, and the dominant soils are freely and imperfectly drained humus-iron podzols often with a strongly indurated B_3 horizon.

In east Sutherland, Barren Red Series rocks give Berriedale Association soils, the main map units being a lowland one dominated by humus-iron podzols and an upland one of peaty podzols, peaty gleys and peat on non-rocky land. A map unit dominated by humus-iron podzols is the main map unit in most of the other associations on ORS-derived parent materials in this region. In the Invergordon-Tain area the most common associations are the Sabhail on brownish till and the Cromarty/Kindeace on reddish till. In the Black Isle the Millbuie Association, on morainic drift derived from sandstone, is extensive, with some Cromarty/Kindeace and some Sabhail. West of Inverness the North Mormond Association — on drifts derived from a mixture of ORS and Moinian rocks — is most common.

The soils on the sandy and silty deposits of the lower raised beaches occur mainly in the Invergordon-Tain area and belong to the Nigg Association; those on raised beach sands and gravels, mainly present in east Sutherland, belong to the Corby Association.

Much of this region is cultivated. Climate limitations are not so severe and LCA Classes range from 2 to 4 with some Class 5 land in the west.

Caithness Plain

The Caithness Plain, occupying the north-east corner of Sheet 3, is a gently undulating lowland region of Old Red Sandstone. Barren Red Series conglomerates and sandstones—mainly of Lower ORS age—form a narrow band on the western boundary of the region. Drifts derived from these rocks are the parent materials of the soils of the Berriedale Association, the main unit being one of peaty gleys, peaty podzols and peat on non-rocky terrain.

The most extensive group of rocks is the Caithness Flagstones of the Middle ORS, comprising limestones, calcareous flags, sandstones and mudstones. Drifts derived from these rocks are the parent materials for the Thurso Association soils. Two types of drift are common, the more widespread being a compact greyish brown till of sandy clay loam texture, and the other a brownish shallow stony drift of sandy loam and loam texture. The main soil map units on the finer-textured till are one dominated by noncalcareous gleys (Thurso series) and another, less extensive, by peaty gleys (Olrig series), while on the shallow stony drift a unit dominated by brown forest soils (Bilbster series) is common. However, the most extensive unit on the Caithness Plain is the deep blanket peat which covers about 40% of the region.

The cultivated land, dominated by noncalcareous gleys and brown forest soils, ranges from LCA Classes 3 to 4; the peaty gleys are in Class 5, and the vast areas of blanket peat are Class 6 land.

Sheet 4 (Western Scotland)

The sheet represents 16 812 km² of west Scotland stretching from Wester Ross in the north to Mid-Argyll in the south, including much of the Central Highlands as well as many islands of the Inner Hebrides. Most of the mapping was new, since only Mull (1:63 360) and Ardnamurchan and Morvern (1:50 000) had been previously published. The landscape is dominated by mountains and moorlands, the more fertile exceptions being Tiree, some coastal fringes and the broader river valleys. The main influence on the climate is the tracking of depressions across the North Atlantic Ocean bringing mild, wet and windy conditions for much of the year. Rainfall varies from over 4000 mm on the western mountains to less than 1000 mm in the north-east.

Geology and Soils

The parent rocks and their derived drifts (forming significant areas) can be divided into:

1. The intensely metamorphosed schists and gneisses of Lewisian and Moinian age.
2. The ancient Pre-Cambrian and Cambro-Ordovician sediments.

3. The Dalradian Series, with its diverse schists, limestones and phyllites.
4. The plutonic intrusions, mainly of the Palaeozoic era.
5. The Palaeozoic and Tertiary extrusive igneous rocks — andesite, basalt and some complexes.
6. Mesozoic sedimentary rocks — limestones, shales and sandstones.
7. Post-glacial deposits.

A fuller account of these seven groups, together with the Soil Associations developed on them, follows:

1. The Lewisian and Moinian rocks underlie much of the north-west Highlands, giving rugged mountains rising to over 1100 m and glacially scoured lowlands with rock at shallow depth. The morainic deposits infilling the valleys are responsible for most of the non-rocky terrain, though they often have surface boulders.

Soils from rocks of Lewisian age — Lochinver Association — are seen in two contrasting groups. The erosion-resistant gneisses of Raasay and around Loch Maree have produced a very rugged landscape with peaty gley soils and frequent rock outcrops. In south-east Skye and between Loch Carron and Loch Hourn the softer chlorite schists give brown forest soils — mainly on steep slopes — though they also provide some farmland.

Arkaig Association (6089 km²) is developed on drifts derived from Moine schists, granulites and gneisses. The commonest units are those with peaty gleys, peat and rock as major components, though some steeper slopes have brown forest soils. Peaty podzols are found on the moraine hummocks. Since much of the area is over 500 m above sea level, sub-alpine and alpine soils are frequent, accounting for 20 per cent of the soils.

2. The Pre-Cambrian sandstones and grits of the Torridon Association give strongly contrasting landforms — high craggy mountains and undulating lowlands with peat flats and occasional rock-knolls. Mineral soils are rare though steep slopes can carry brown forest soils. The Association accounts for 6·3 per cent of the sheet (1057 km²), the largest areas being in Applecross, Wester Ross, Skye, Rhum and Colonsay. Most of the soils are peaty gleys, though some steep coastal slopes have brown forest soils.

The soils of the Durness limestone have been mapped in the Inchnadamph Association. Although the terrain is rock controlled, the brown calcareous soils give a more subdued grassy landscape, with superior grazings and some crofting, in direct contrast to the surrounding land. Unfortunately, these fertile soils cover only 0·1 per cent of the area (21 km²).

3. A wide range of lithological types are found within the Dalradian series of rocks, and a number of associations have been distinguished on the more distinctive varieties:

(a) Deecastle Association — drifts derived from calc-silicate rocks and impure limestones.
(b) Durnhill Association — drifts derived from quartzites.
(c) Foudland Association — drifts derived from slates and phyllites of low metamorphic grade.

(d) Strichen Association — drifts derived from phyllites and quartz-mica schists of high metamorphic grade.

(e) Tarves Association — drifts derived from epidiorites and chlorite schists.

(a) Soils of the Deecastle Association are shallow brown forest soils and brown rankers with high grazing value pastures. The Association is confined to Lismore Island and north Lorne, occupying only 63 km², but forming some of the best grazing ground of the sheet area.

(b) The soils of the Durnhill Association are peaty and stony and carry a sward of poor grazing value. Topography varies from the scree-covered slopes of the Mamores at over 1000 m to the rough rocky terrain of south Skye and Appin and the gently undulating moorland of Jura.

(c) A silty texture is the prime feature of the soils of the Foudland Association (688 km²) and under the high rainfall, gleying is present even in the brown forest soils. The islands of Lorne are strongly ridged and are composed largely of slate, giving good stock-rearing land. Further east, where phyllite is the dominant rock, fine sandy loam tills occur close to Loch Fyne and some of these are cultivated.

(d) The Strichen Association is confined to the area south-east of the Great Glen Fault and occupies 10·8 per cent (1759 km²). Topography varies from the extremely rocky Arrochar mountains which rise above 1000 m to the strongly ridged low-lying areas of Knapdale. A great variety of soil types are present, but as with most acid parent materials in west Scotland, peaty gleys form the largest soil component.

(e) The Tarves Association soils are developed on drifts derived from metamorphosed igneous rocks of intermediate and basic composition — the "epidiorites". They are found around Loch Awe and although often shallow and rocky, mineral soils form a significant percentage of the association.

4. The granite intrusions, principally of the Palaeozoic era, give soils of the Countesswells Association (1317 km²). The largest plutons are those of the Ross of Mull, Morvern, Ben Nevis, Loch Etive and Rannoch Moor. With the exception of those developed on the deeper morainic drifts, soils are shallow and stony, the main soil type being the peaty gley.

The main area of Insch Association soils (0·5% of the sheet) is found in Ardnamurchan on the gabbroic ring dyke complex. Some crofting areas are seen on the more easily weathered rocks with brown forest soils, but the intrusions form a rocky landscape.

5. The Palaeozoic and Tertiary extrusive rocks and the complexes form the parent materials of three associations.

(a) Darleith Association — drifts derived from basaltic rocks.

(b) Sourhope Association — drifts derived from andesitic rocks.

(c) Torosay Association — drifts derived from basic cone sheets and metamorphosed country rocks.

(a) The third most extensive Association on the sheet — Darleith Association — covers 9·2 per cent of the area and forms much of the

islands of Skye, Canna, Eigg and Mull. Brown forest soils, in a slightly rocky, terraced landscape, are common at low altitudes, but the extensive plateau between 200 m and 400 m is dominated by peaty gley and peat soils, while the steeper slopes in this range have peaty podzols.

Small areas of deep loamy drift in Mull and Skye have been cultivated, low ground pastures with a high grazing value are common, and the remaining hill land is used for rough grazings and forestry.

(b) The area between Loch Etive and Loch Melfort is occupied by the Sourhope Association (345 km^2). Peaty gleys and peat are the main soils on the slightly terraced plateau landscape at an elevation of 200-300 m. The steep slopes closer to sea level have brown forest soils and provide good grazings where they are not wooded.

(c) The Torosay Association (516 km^2) occurs in Mull, Skye, Ardnamurchan and Glencoe. The parent material is derived mainly from cone sheets of basaltic composition, but soils are stony and the landscape irregular compared with the loamy textures and terraced landform of the Darleith Associations. Brown forest soils are limited to steep lowland slopes, while peaty gleys in gently sloping areas grade to peaty podzols and subalpine podzols with increasing gradients and altitude.

6. Soils derived from rocks of Mesozoic age have been mapped into two Associations, the Staffin Association when fine-textured rocks contribute the bulk of the parent material and the Inchkenneth Association when sandstones form the major component in the drift.

Fine-textured drifts derived from Jurassic shales form extensive areas of Staffin Association in north Skye and west Tiree, although only a small portion can be cultivated.

Soils developed on the sandier Mesozoic sediments are found in the Broadford and Elgol regions of Skye, Mull and Colonsay. Inchkenneth Association, although it accounts for only 0·4% of the area, has sufficient brown forest soils and non-calcareous gleys to support the agriculture of many crofting communities.

7. The post-glacial deposits give soils belonging to the following associations:

(a) Corby Association	— fluvioglacial and raised beach sands and gravels derived from acid rocks.
(b) Fraserburgh and Links Associations	— aeolian sands with and without shell fragments respectively.
(c) Gruline Association	— fluvioglacial and raised beach sands and gravels derived from a mixture of acid and basic rocks.

In addition, alluvium, peat and bare rock/scree map units have been distinguished.

Though accounting for only 2 per cent of the sheet, Corby Association soils give arable and crofting land in areas where there would otherwise be no possibilities for farming apart from rough grazings. Particularly important are the areas on Tiree, north-east of Fort William along the Great Glen, and the many small occurrences in Lorne. The landscape

varies from level raised beach to fluvioglacial terraces and strongly hummocky ice-contact deposits.

(b) The similarities of the Fraserburgh and Links Associations are the dune and machair topography, sandy textures, the mode of formation of the parent material and their liability to drought and erosion. In direct contrast, however, the Fraserburgh Association has brown calcareous soils with a high pH, while the Links Association has immature acidic podzols. On Tiree the undulating machairs of the Fraserburgh Association provide natural pasture with a high grazing value, while some sheltered areas are cultivated.

(c) The Gruline Association is broadly similar to the Corby Association, but contains more basic igneous material. It is distributed around the Tertiary volcanic centres, mainly in Ardnamurchan and Mull, and also close to the Lorne Volcanic Plateau.

Alluvium of variable texture, drainage and provenance has a wide distribution. Locally important flats are seen at Kinlochmoidart, Morvich, Dalmally and in the broad eastern valleys such as Strathglass. On many occasions, especially in the west, it provides the only arable ground of the region in which it occurs.

Peat (>50 cm deep) forms a significant proportion of many map units, but accounts for only 4·3 per cent of the area as a separately delineated unit. A broad distinction between basin peats and hill peats has been made. The main basin peats are at Claish Moss on Loch Shielside and on the Moine Mor near Crinan, while the largest stretches of hill peat are on north Skye and on the hills to the south-east of Loch Oich.

Land Capability for Agriculture

Present land use is largely restricted to rough grazings for sheep and deer, forestry and recreation. Arable ground in the west is of very small extent and is rarely better than Class 4 due to the restrictions of climate alone. It occurs on the noncalcareous gley soils of Islay, Mull and Skye, and throughout the area on small stretches of raised beach, outwash and alluvial deposits. Some of the alluvial eastern straths have a considerably warmer and drier climate, giving a little Class 3 land.

Class 5 land, suitable for improvement to grassland, is widespread on slightly rocky terrain with brown forest soils, most commonly on basalt. Other soils in this category include raised beaches which are too gravelly to cultivate, most of the machair land which is liable to erosion and drought, and some peaty soils in lower rainfall areas — though more careful management and maintenance is required than on the mineral soils.

By far the largest proportion of the sheet is Class 6 land, usable only as rough pastures. The summits of the higher mountains and areas dominated by bare rock and scree are of little or no use to agriculture and have thus been designated as Class 7.

Sheet 5 (Eastern Scotland)

This sheet with a total land area of approximately 24,800 km² includes most of the Grampian Highlands and the adjoining lowlands. The

diversity of the rock types present, the glacial history, with consequent landforms and soil parent materials, and the wide climatic range have, in combination, resulted in a large number of soil association groupings (59) and soil mapping units (233).

The sheet can be conveniently described in four regions:

Strathmore and Fife. Lying south and east of the Highland Boundary Fault this region is underlain by rocks of the Upper Palaeozoic era. It includes some of the best arable land in Scotland.

Tills derived from Lower O.R.S. sediments — sandstones, mudstones and conglomerates — occupy the Vale of Strathmore. Carboniferous sandstones, shales, limestones and coals constitute the source materials of the regional till of Fife. In general, the tills from O.R.S. sediments tend to be somewhat coarser-textured (sandy loam to sandy clay loam) than tills derived from Carboniferous sediments (sandy clay loam to clay loam). In valleys, depressions and other low-lying situations the large quantities of meltwater present during deglaciation modified the tills, resulting in higher sand content in the upper parts of the solum.

Fluvioglacial sands and gravels, in the form of both mounds and terraces, figure prominently in the landscapes of Stratheden and Strathallan and the Plain of Kinross. Sandy raised beach deposits fringe much of the coastline of Fife and Tayside. In contrast, low raised beach silts and clays, the parent material of the renowned Carse soils, have been laid down in the sheltered estuaries of the Firths of Forth and Tay.

Igneous rocks characterise the higher ground of the region. Andesitic and basaltic lavas with associated tuffs of Lower O.R.S. age form the Ochil Hills and the Sidlaws. The Lomond Hills and the low hills of East Fife are composed of doleritic and basaltic sills of Carboniferous age.

Brown forest soils are, by far, the most common soils within the region. In the hill areas, where soils are often shallow and rock may outcrop, they are accompanied by related brown rankers. The finer-textured tills give rise to brown forest soils with gleyed B and C horizons due to impeded drainage. With the exception of the Carse soils, poorly drained soils are of limited extent in this region. Podzols, mostly cultivated, occur on fluvioglacial parent materials and on some deeper-washed tills.

The Moray Firth Lowlands. This region of coastal lowlands fringes the Moray Firth westwards from Buckie. It forms a narrow belt with a maximum width of 20 km but only 3 km wide at Inverness. The region is underlain mainly by sandstones of Middle and Upper O.R.S. age. Tills derived from these rocks occur widely on the slopes of the southern margin but only sporadically elsewhere, as the lower ground has a widespread cover of fluvioglacial sands and gravels together with raised beach and other Recent deposits. Soils on glacial materials are mainly cultivated podzols; soils on Recent deposits generally have immature profiles.

Buchan and Lower Deeside. This region, mostly lying below 250 m, is triangular in shape with a rather ill-defined inland boundary stretching from Buckie to Stonehaven. The bulk of the region is underlain by granite

and various acid metamorphic rocks of the Dalradian series, mainly mica-schist, quartz-schist, and andalusite-schist, quartizite and acid gneiss.

Along the north-east coast red clay till and glaciolacustrine deposits overlying acid metamorphic rocks probably have their origin in offshore O.R.S. sediments. Inland there is a zone of undulating topography with stony sandy loam till mostly derived from a variety of rock types. This gives way westwards to smoother dissected topography and a belt, 30 km broad, of homogenous drift derived from andalusite schists, slates and phyllites. Soils here are frequently developed on weathered rock. A parent material containing the above argillaceous rocks, together with O.R.S. sediments, is found in the Turriff area and provides some of the best soils of the region. High quality soils also occur in the Insch valley where a basic igneous intrusion composed of gabbro has been deeply weathered. Coarse, often gritty, sandy loam till derived from granite and gneiss dominates the southern half of the region and this parent material with its boulders and intense induration corresponds with many of the poorest agricultural areas.

Brown forest soils are developed on the richer parent materials, those with a basic igneous component, and on some of the fine-textured coastal deposits. In the last case the brown forest soils have gleyed B and C horizons. The most common soil type of this region, however, is the podzol. Its pre-eminence here may be attributed mainly to the inherent poverty of the acid parent materials, although the less favourable climate is an ancillary factor. Most of these podzols are cultivated but still retain the strong brown colours of the B horizon. At higher elevations, and on the most acid parent materials, such as granite and quartzite drifts, peaty podzols have developed.

Compared with the two previously described lowland regions, Buchan and Lower Deeside has a considerably greater proportion of noncalcareous gleys. These poorly-drained soils occur on gentle slopes and receiving sites in the till-covered areas.

Grampian Highlands. This region, the largest within the sheet, has sharp north and south-east boundaries but, to the north-east, grades into the Buchan lowlands. The elevation of the hill tops attains 1200 m in the Cairngorms but falls to 400 m to the north and east.

Geologically, the north and west Grampians are composed of Moinian rocks — a monotonous series of quartz-feldspar granulites with occasional mica-schists. Dalradian rocks, a varied sequence of mica-schists, quartz-schists, acid gneisses quartzites, slates and limestones, lie to the south and east. Granites have been intruded into the metamorphic rocks of both the Moine and Dalradian series.

Glaciation accounts for most of the spatial variation in landforms and drifts. Glacial erosional activity was, in general, more intense in the west, the ice having flowed radially outwards from the Rannoch Moor ice-cap. The rugged rocky hills of the west contrast with the solifluction-rounded hills of the east. Coarse-textured tills occur in broader valleys and along the northern edge of the region, but most areas are covered by a thin stony

drift. Hummocky moraines are widespread from the lowest valleys to the highest corries. Fluvioglacial sands and gravels are confined largely to major river valleys. Although geology and glacial history have controlled the distribution of parent materials, climate is the vital factor in explaining the distribution of soil types. In the west where annual rainfall may be as high as 2500 mm, peaty gleys are dominant, whereas towards the north and east, with rainfall dropping as low as 900 mm, soils of the podzol group are pre-eminent. With increasing altitude rainfall increases and temperature falls. Biotic activity decreases and organic matter builds up as peat. On the mountain tops freeze-thaw processes are seasonably active in the soil.

Soil units within each parent material grouping have been separated not only on the basis of component soils but also on a degree of rockiness and the presence or absence of peat. This latter feature is closely related to slope, with peat becoming rare on slopes greater than 15°.

Brown forest soils are uncommon in the region. They are found, however, on the steep, often rocky, slopes in the south-west, associated with richer parent materials of the Dalradian rocks. Noncalcareous, humic and peaty gleys occur here on the gentler slopes. To the north-east, where slopes tend to be smooth, non-rocky and convex, humus-iron podzols on the steep slopes regress into peaty podzols on the gentler slopes above.

On the more acid Moine rocks the peaty gley which characterises the lower hill slopes of the west is replaced northwards and eastwards by peaty podzol. This transformation is mirrored by the increase of boreal heather moor at the expense of bog heather moor. Humus-iron podzols in the Moine are limited to steep slopes at low elevations.

Peat in the wetter west is ubiquitous and is generally in intimate association with the other soils, especially peaty gleys. To the north and east, however, it often forms discrete areas. Here it may lie in the high valleys and cols or, as larger areas, can blanket plateaux and hill tops. For example, north of Carrbridge much of the gently sloping land and, in the eastern Grampians, many of the broad summits below 800 m, are covered by peat. The strongly hagged peat blanket of the Monadliaths is sporadically broken by rocky knolls with subalpine soils.

The mountains of the south-west have long steep slopes of subalpine soils reaching to the peaks, but to the north-east, the broader summits of the mountains are capped by alpine soils. At the centre of the sheet the Cairngorm Plateau, a massive granite pluton, is too high and exposed for peat development. Here is found the greatest expanse of alpine soils in Britain.

Land Capability for Agriculture

The only sizable area of Class I land reproduced at the 1:250,000 scale on Sheet 5 occurs near Carnoustie where there are deep topsoils on raised beach material. There are, however, significant areas of Class 2 in Strathmore and in East and South Fife on both raised beach and till soils. The water-modified tills are especially favoured for arable agriculture; the washed top horizons result in minimum trafficability problems and poaching

risks, while the heavier till at depth ensures a supply of moisture throughout the growing season. Further west textural and wetness problems associated with increasing rainfall reduce the potential of the till soils to Class 3.

Despite the excellent climate of the Moray Firth Lowlands, Class 3 dominates here, the main limitations being the tendency to drought of the sandy soils. Wind erosion, another problem, is most damaging in springtime and may necessitate the resowing of some fields. A few small areas of Class 2 do exist in the region, mainly on alluvium, glacio-lacustrine soils and on some fluvioglacial deposits with deep topsoils.

Class 3 land accounts for more than two-thirds of Buchan and Lower Deeside. Soil limitations, such as stoniness and the rooting depth limitation of induration, prevent all but a few areas being classified higher. The poorer climate is, by itself, a limiting factor.

Within Class 4 is the poorest arable land of the sheet area including soils on intractable parent materials, such as the bouldery granite and quartzite drifts and some gravelly fluvioglacial deposits. Also placed in this class are lowland soils with severe drainage problems, foothills with their troublesome slopes, and much of the arable land in straths and glens which penetrate the Grampian Highlands.

Class 5 contains most of the marginal land of the hill areas, where mechanised improvement for grass swards is possible, but arable cropping is inadvisable, often because of slope patterns, rockiness or organic topsoils. The Sidlaw Hills, the Lomond Hills, and the lower hills of the Ochils provide examples. Peaty podzols of the north-east Grampians are placed in this class as are improvable coastal dunes and the basin peats of Buchan.

The bulk of the higher hill areas of the Grampian Highlands constitute Class 6. The agricultural value of the land, as rough grazings, is dependent upon the vegetation communities which relate closely to the soils. Good grazings exist in the south-west Grampians where bent-fescue grassland is associated with the brown forest soils developed on Dalradian rocks and their drifts. More exotic communities are found on the Blair Atholl limestone. Elsewhere, and in the area of Moine rocks especially, the best grazings are localised, being confined to the steep slopes.

Moderate grazings, for example, *Nardus* grassland, occupy a variety of situations from valley floors to the subalpine zone but, in total, account for only a small proportion of Class 6. The most extensive communities of the Grampians, blanket bog and Boreal Atlantic and bog heather moors, afford only poor quality grazings.

Class 7 is restricted to mountain tops mostly above 700 m and to strongly hagged peat.

Sheets 6 and 7 (South-West and South-East Scotland)

Many of the principal features of the soils, geology, landform and climate are common to the areas represented on both map Sheet 6 and map Sheet 7 and a joint account is presented of the 1:250 000 survey. Approximately 30 000 square kilometres are encompassed and extend from the

Hebridean Islands of Islay, Jura and Colonsay to the Mull of Kintyre and south Argyll in the west through the area around Ben Vorlich and Ben Venue to the Firth of Tay in the east; to the south are the Midland Valley and Southern Uplands of Scotland bordered by the Solway Firth and the boundary with England.

Two of the principal geological faults of Scotland, the Highland Boundary Fault and the Southern Uplands Fault, divide the area into three natural physiographic regions, the Highlands, the Midland Valley and the Southern Uplands. Rocks of a wide variety, mainly pre-Cambrian in age, are represented in the Highlands. On the Rhinns of Islay, Lewisian schists and gneisses outcrop adjacent to Torridonian sandstones which also underlie Colonsay, but most extensive are the quartzites, quartzose schists, phyllites and slates of Dalradian metamorphic provenance. Granite forms the high ground of northern Arran and Permian sandstones much of the southern part of the island.

In the Midland Valley, a down-faulted block between the Highlands and Southern Uplands, the rocks belong principally to the old Red Standstone and Carboniferous systems. O.R.S. sandstones and conglomerates underlie southern Strathmore and also outcrop at Largs and around Maybole. Contemporaneous andesitic lavas make up the Ochils. South of Stirling the sedimentary rocks are shales, sandstones and calciferous sandstones with coals of the Carboniferous period. Dating also from this epoch are the basalts of the Campsie and Kilsyth Hills and the high ground of north Ayrshire, and the many smaller outcrops of basic intrusive rocks.

The Southern Uplands Fault is prominent throughout much of its length, being marked by deep narrow valleys cut by streams excavating fault-shattered rock or by the steeply sloping ground, giving way to the steeply bedded Ordovician and Silurian greywackes and shales; rocks hardened by low grade metamorphism form the smooth round hills of the Southern Uplands. Spilitic lavas and serpentines at Ballantrae and conglomerates rich in basic igneous-derived material at Barr form other distinctive rocks of Lower Ordovician age. The rugged montane landscapes of the 'Galloway granites' resemble in many aspects the Highlands rather than the Southern Uplands. Within or associated with greywacke uplands are a number of basins underlain by younger softer rocks, calciferous sandstones and shales in the Merse of Berwickshire, sandstones and breccias in the Permian basins of Dumfriesshire and Carboniferous sediments in the Nith Valley at Sanquhar. Andesites and Carboniferous sandstones form much of the high ground along the English border.

Ice-movement has been the predominant agency forming the superficial deposits on which the present soils have developed. In the Highland area an outstanding feature of the drifts is the contribution of material dredged from the sea bed by ice emanating from the Clyde. Lodgement till in the Midland Valley lowlands is thick and extensive while sands and gravels left by glacial melt-waters are widely distributed, but of limited extent. On the uplands superficial deposits are generally thin, shallow and stony.

Climatic variation is related to the physiographic regions and the interaction of upland and lowland with the prevailing south-west to west airstream. Directly in the path of the winds from the Atlantic, the hills of Argyll and the western Southern Uplands receive heavy rainfall and precipitation reaches 2500 mm per annum. To the east rainfall decreases and the lowlands of Berwickshire, the Lothians and Fife enjoy moderate levels (750 mm per annum) of precipitation. Altitude is also the principal factor determining variation in average annual temperatures throughout the regions.

In all, 73 soil associations — in a few instances groups of associations — have been recognised and mapped into 353 map units having distinctive soil patterns, landforms and associated plant communities. In the Southern Uplands the Ettrick Association comprises the soils developed on greywackes and shales and their derived drifts and is one of the most extensive and varied associations in Scotland. At moderate and low elevations brown forest soils have been mapped in units characterised by free and imperfect drainage, the presence or absence of rock outcrops, landforms with drumlins and irregular outcropping rock and soils with water-worked parent tills. Galloway landscapes of drumlins, valley moraines, fields of roches moutonnées and similar glacially moulded rock scattered through extensive deposits of peat form distinctive map units. Eastward from Galloway the Southern Upland hills are strongly dissected with brown forest soils on the steep lower slopes and podzols on the rounded summits. Peaty and noncalcareous gleys occupy some of the broader valley bottoms and on the summits of the highest hills, such as Merrick or Broad Law, subalpine soils have been mapped.

There are also a number of other important if less extensive associations in the Southern Uplands. The Sourhope Association on the andesitic lavas of the east Border hills comprises a relatively simple soil and map unit pattern of brown forest soils and podzols on smooth rounded hills. The undulating lowlands of the Merse of Berwickshire are occupied by brown forest soils (with gleying) developed on the clayey tills of the Whitsome Association. Upper Old Red Sandstone sandstones and marls and their derived drifts carry soils of the Hobkirk Association and conglomerates and sandstones of similar age are the parent rocks of the Lauder Association; in each, brown forest soils form the predominant map units. The Carter Association of the Central Borders consists mainly of peaty gleys and noncalcareous gleys on fine-textured tills derived from sandstones of the Calciferous Sandstone series. On the undulating lowlands of east Dumfriesshire the brown forest soils with gleying and noncalcareous gleys of the Canonbie Association are developed on mixed tills derived from Carboniferous and Permian sandstones and finer sediments. A red-brown clay loam till covering most of the Rhins of Galloway carries brown forest soils with gleying of the Rhins Association.

A range of important and widespread associations occupy the Midland Valley. However, the Carboniferous sandstones, shales and limestones are the most extensive sedimentary rocks and the derived drifts are the parent

materials of the Rowanhill, Giffnock and Winton Associations which, in the present survey, are formed into one group of map units. The thick grey, greyish brown and brown clayey tills occupy much of the undulating lowland and carry soils slowly permeable to moisture, with strong gley features; of the eight map units those with noncalcareous gleys and brown forest soils with gleying are much the most extensive. Soils developed on mixed tills derived from Carboniferous sediments and other rocks form a number of smaller associations of which the Kilmarnock Association with basalt component in the parent till is perhaps the most important.

The basaltic lavas of north Ayrshire and the Kilsyth and Campsie Hills are the parent rocks of the Darleith Association in which a wide range of soils and landforms have been mapped in 13 map units; characteristically the brown forest soils are relatively uniform in colour with profile depth and have strong well-developed structure. The soils of the Sourhope Association of the Ochils and north Fife are similar to the andesite-derived soils of the Southern Uplands.

The undulating lowlands of Strathmore are occupied by O.R.S. sandstones and their derived drifts, the parent materials of the Balrownie Association; brown forest soils and brown forest soils with gleying are the predominant major soil subgroups with humus-iron podzols, peaty podzols and peaty gleys occurring on uplands adjacent to the Highlands. Other soils on drifts from Old Red Sandstone rocks are the Glenalmond Association of Ayrshire from sediments of the Lower Old Red Sandstone and the Largs, Kippen and Hobkirk Associations from Upper Old Red Sandstone strata.

The gley soils developed on the estuarine raised beach silts and clays of the Carse of Stirling are the most extensive group of soils on materials of Recent origin. Around the coasts, coarse-textured raised beach deposits carry brown forest soils of the Carpow, Panbride and Dreghorn Associations and fluvioglacial sands and gravels derived from a variety of rocks form the parent materials of the Darvel, Doune, Eckford, Innerwick and Gleneagles Associations.

In the Highlands and Hebridean Islands the Lewisian schists and gneisses of the Rhinns of Islay are mapped in the Lochinver Association and form peaty rocky landscapes, little differentiated from those on Torridonian sandstones (Torridon Association) which adjoin it. Much of the remainder of Islay, Jura and north Kintyre, although appearing less rugged, is developed on quartzite (Durnhill Association) and is also dominated by organic soils. The brown forest soils and gleys developed on the " limestones " of Islay are mapped in the Inchnadamph Association as they have no free calcium carbonate. However, they form a better resource than those derived from many of the older acidic rocks and are widely used as improved pasture.

Soils with high silt (>40%) and fine sand contents derived from slates, phyllites and mica-schists of low grade metamorphism constitute the Foudland Association of Islay, Lock Fyne, Bute and the southern banks of Loch Lomond. Brown forest soils and calcareous gleys provide useful land at

lower altitudes, but are quickly replaced by peaty gleys, peaty podzols and peat. In Cowal and near Loch Lomond, however, many of the hill soils carry white bent grassland and form better grazings as do the soils developed on mica-schists (Strichen Association) in adjoining areas.

Arran is clearly divided into two parts, the north dominated by the rocky, peaty granitic units of Countesswells Association, the south with drifts derived from Triassic (Arran Association) and Permian (Mauchline Association) sandstone. Southern Kintyre has deep, red tills, formed from schists and red sandstone from the sea bed (Kintyre Association). The association extends across southern Jura and Islay only to be replaced on the Rhinns of Islay by a clayey till probably from Mesozoic sub-sea strata. The tills carry gley soils which support pastoral farming enterprises. Only where re-sorting gives extensive outwash sands, gravels and alluvium, for example the haggan of Campeltown and southern Bute, does arable land break up the grassland to any significant extent.

The agriculture of the area is highly diversified and, in its broad patterns, related to climate. On the lowlands of the west and south-west the high rainfall equability of temperature and oceanicity of climate favours grass growth rather than arable crops. Ayrshire and Dumfries and Galloway are renowned for the quality of their dairy industry. In the lowlands of the east precipitation is less, winters harsher and summers hotter and much farming is based on arable cropping, with wheat and barley growing an important element, often complemented by fat cattle production. Timothy grass leys for the production of hay and short breaks in grain crops has been the traditional cropping pattern on the Carse of Stirling and is well-adapted to the soil conditions. Sheep and cattle, extensively managed, are the main enterprises on the hills of both the Southern Uplands and Highlands. In the marginal areas, such as the eastern Southern Uplands, where the proportions of improved land to hill are greater, management of sheep and cattle enterprises is more intensive.

Present land usage is reflected to a considerable extent in the general pattern of land in the classes of the Land Capability Classification.

Class 1 and 2 land is confined mainly to parts of the Tweed Valley, Lothian and Fife. Land in Class 3, however, is widespread throughout the lowlands and in the drier east many of the brown forest soils with gleying developed on slowly permeable clay loam tills have been placed at the top of the class, and these with the small areas in Classes 1 and 2 are the best land in the area. Similar soils under the higher rainfall of the west are at the lower end of Class 3, while the noncalcareous gley soils of the western and central parts of the Midland Valley are in Class 4. These slowly permeable fine-textured soils demand systematic under-drainage, adequate housing for cattle so that stock can be removed at times when the danger of poaching is severe, and restriction of cultivations to periods when soil structural damage will be least. In the uplands where climate and slope are the principal limiting factors, Class 5 land provides some of the most valuable grazing on stock-rearing farms, but much land with a potential for improvement remains as rough grazing. The higher hills and some exten-

sive lowland peat deposits form large areas of Class 6 land. In the valleys of the Southern Uplands, however, where severe slopes prevent improvement, the bent-fesque pastures nevertheless provide good grazings. There is little Class 7 land.

Special Surveys

Barony Agricultural College Farm and Stenmuir Farm, Dumfriesshire. At the request of the Principal of the College the soils of a total area of 160 hectares were surveyed at a scale of 1:25 000 and a map and report prepared. The parent materials are dominated by the fluvioglacial sands and gravels of the Yarrow Association and by the recent gravelly and loamy alluvium deposited by the River Ae. The fluvioglacial deposits are both moundy and terraced and the soils are extremely stony and difficult to cultivate. Good quality grass, mostly for silage, is grown on the predominantly well-drained alluvial fields, but the climate is unfavourable to intensive cereal growing.

Kinlochbervie Estate, Sutherland. A 1:50 000 map showing the distribution of peat on the estate was prepared.

Cambusmore Estate, Sutherland. A soil map of the estate at the scale of 1:50 000 was supplied at the request of the estate factor.

Cowie, Stirlingshire. A soil map and report in connection with sand and gravel extraction at the request of D.A.F.S. 801

Vegetation Surveys

An account of the plant communities of the Cairnsmore of Fleet and Creetown District has been prepared to accompany the map of the vegetation. General chapters on methods, physical setting and climate have been included. The chapter on geology and soils is being prepared by Mr C. J. Bown.

A paper on the woodlands of North Scotland[1] was written and offered to Phytocoenologia for publication. This has been accepted by the journal and is now at the galley proof stage.

Tables of the plant communities of the Gairloch District in Wester Ross were drawn up preparatory to mapping the vegetation. The main area is occupied by Erico-Sphagnetum papillosi, blanket bog, and Narthecio-Ericetum tetralicis, bog heather moor, in the class Oxycocco-Sphagnetea, but in the lowland region Blechno-Quercetum, Atlantic oakwood, is an important community. Mapping the vegetation began in the latter half of May and continued to the beginning of September. The major part of the mapping was completed and there remains about a fortnight's work for next season, together with some further sampling of unrecorded communities.

Ten more samples of plant communities were collected during the summer and placed in the Tüxen Garden. Some maintenance difficulties are being experienced due to the attentions of ducks, the severe drought in Aberdeen this summer and the effect of possible atmospheric pollution on the lichens.

Work by the Aberdeen University Press on the bulletin of revised and additional tables of Scottish plant communities[2] is nearing completion and the date of publication is imminent.

Field work associated with the 1:250 000 Upland Survey has now been completed with a visit to the Outer Hebrides to record the plant communities of Sheet 2. From the vegetation records gathered throughout the country over the last three years, a list of plant communities associated with the soil mapping units has been compiled for inclusion in the Key of each 1:250 000 soil map. The legends for all seven sheets have been completed. A short general description of the vegetation of each area is being prepared for inclusion in the handbooks.

Monitoring of the heather regeneration plots in Glen Artney has continued and the changes in vegetation cover were recorded in May and August. A significant increase in the cover of heather (*Calluna vulgaris*) both as growth from old stems and from invasion by seedlings is now observable in a number of the plots subjected to treatment with a 'maximum kill' solution of Delapon (8 oz/gal). In the plots treated with a weaker solution (1·5 oz/gal), the original sward of flying bent (*Molinia caerulea*) is rapidly reforming and effectively preventing any potential colonisation by heather seedlings.

The system for the assessment of the relative grazing values of plant communities has been revised for inclusion in a monograph on Land Capability for Agriculture Classification. Values for eighty-two communities have now been listed. 802

Soil Micromorphology

During the current year some time has been spent on preparatory work associated with the sixth International Working Meeting on Soil Micromorphology which was held at University College, London, from the 17th to 22nd of August, 1981. An illuminated panel, demonstrating the relationships between an undisturbed soil monolith, a polished sheet cut from the monolith, a full sized (75 x 15 cm) soil thin section also cut from the monolith, and a set of standard sized 7·5 x 5·5 cm soil thin sections, was exhibited at this meeting. It has subsequently been agreed that this item should be transferred to the International Soils Museum at Wageningen in the Netherlands.

Laboratory work has included the preparation of some 110 soil thin sections. A further 180 undisturbed soil samples have been collected during the latter part of the 1981 field season to continue the work in progress on the processes responsible for clay illuviation in Scottish soils.

A paper on 'the general effects of early agriculture on the soil profile'[3] was presented at a symposium on 'the impact of aerial reconnaissance on archaeology' held at the University of Nottingham in December, 1980. An account of the soils at Scord of Brouster in Shetland[4] has been prepared for inclusion in a monograph on excavations at Scord of Brouster which is presently being compiled by Dr A. Whittle of University College Cardiff. 804

Other Work

There has been an increasing level of collaboration with the Department of Agriculture and Fisheries for Scotland and with the three Scottish Colleges of Agriculture, particularly in consultations on the land capability assessment in connection with the 1:250 000 mapping project, and on specific sites in the course of inquiries. Soils information has been provided for field drainage and reclamation schemes and there has been more involvement with the National Coal Board on the restoration of open-cast mining sites.

Soils information has been supplied to the Natural Environment Research Council in relation to proposed developments in the Cairngorms, to the Highland Regional Council and Highlands and Islands Development Board, in connection with new roads and other schemes. A report on the soils, vegetation and climate of Islay has been supplied in connection with EEC grant aid, and of Arran to assist in the setting up of a field centre. Liaison has continued with the Nature Conservancy Council, the Forestry Commission, other Research Institutes, the Soil Survey of England and Wales, particularly in land capability assessment, and plant community identification and grazing evaluation, and with other Departments of the Institute. Assistance in field excursions has been provided for University student parties, notably the Forestry Department, Aberdeen, Geography Department, St Andrews, and Biological Sciences, Dundee. Talks on the work of the Soil Survey have been given to parties of visitors. There has been an increasing number of requests for information and assistance from farmers, managers, research workers, students and members of the public.

The Department played a major role in organising and conducting the excursions for the autumn meeting of the British Society of Soil Science in Aberdeen and in compiling the handbook. The Survey also provided a tutor and judge for a Soil Assessment Competition organised by the Young Farmers' Clubs and sponsored by British Petroleum.

A senior surveyor gave an interview on the progress of Soil Survey in Scotland for a Grampian TV programme and spent two weeks filming on location with the Aberdeen University Television and Film Department in connection with the production of a film on land capability.

A paper on the soils of Culbin Forest[5] has been published; papers on major-element re-distribution in three soil profiles[6], the soils of the Inner Hebrides[7] and native pinewood soils in Abernethy Forest[8] have been accepted for publication. Papers on the soils of Loch Garten Nature Reserve[9] and on computer processing of soil profile data[10] have been submitted together with a note on the European SAR-581 experiment[11].

801, 802, 804

Maps, Memoirs and Cartography

The following 1 inch maps have been published in both flat and folded versions, Sheet 39 Stirling (both Soil and Land Use Capability)[12, 13], combined Sheet 66/67 Banchory and Stonehaven (Soil reprint)[14]. Soil and Land Use Capability maps on the 1:50 000 scale have been published for

the following sheets, Ardnamurchan and Morvern[15, 16], Orkney-Northern Isles[17, 18], Orkney Mainland[19, 20] and Orkney-Hoy[21, 22].

Colour proofs of 1 inch Sheet 47 Crieff (Land Use Capability) and Sheet 75 Tomintoul (Soil) have been examined and returned to Ordnance Survey for final printing. The colour proofs of 1 inch Sheet 75 Tomintoul (Land Use Capability) has been examined, but final printing has been suspended until final field checks have been carried out in conjunction with parts of Sheet 85 to the north.

Work on the 1:250 000 topographic base maps is complete. The scribing of the soil boundaries for all seven sheets is now finished and work is on schedule at Ordnance Survey for the production of colour proofs.

Compilation has started on the 1:250 000 Land Capability for Agriculture maps. Most of the lines on these sheets will be directly derived from the soil lines. All scribing of the Land Capability sheets will be undertaken at Soil Survey drawing office.

The 1:250 000 maps will be published together with explanatory handbooks. These will be printed in Aberdeen from typesettings supplied by Soil Survey. Work has started on the preparation of diagrams to be included in the handbooks.

A limited circulation map of the Soils of Craibstone Farm, Aberdeen, has been prepared on a 1:5 000 scale. 801

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10. TECHNICAL SERVICES

A. W. Stuart

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

Several new items of equipment have been acquired, including an Analytical Projector to enable the study of time-lapse film, a Tilting Arbor Dimensioning Saw, which has increased the work-handling capabilities of the Joinery/Building Maintenance section, and a Portable Hydraulic Work Platform, which can provide access to a height of 35 feet. This latter piece of equipment has proved to be a great asset in terms of building maintenance.

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

INSTRUMENTATION

A few examples of the wide variety of tasks undertaken by the Section are mentioned below:

Spectrochemistry. Development and manufacture of a Mark II Plasma Torch, Stainless Steel adaptor flanges for Mass Spectrometer vacuum pumps, a gear box unit for an Optica Spectrometer used for wavelength scanning in conjunction with a microprocessor controlled stepper motor. A jewelled nebulizer for the Plasma Torch is under development.

Soil Organic Chemistry. Construction of a perspex constant pump flow vessel, pressurised by inert gas and a miniature Phytotron for use with time-lapse photography experiments. An automated sample change unit for use with the Philips X-ray Spectrometer for Mineral Soils is under construction.

ELECTRONICS

During the year the greater part of the Section's time has again been needed for maintenance and repair work to laboratory equipment.

The increasing use of microcomputers in the laboratories has been reflected by requests for interface circuit design, and two projects involving such interfaces are now nearing completion; *viz.* the automation of the Dionex Ion Chromatograph for the Department of Peat and Forest Soils and the automation of the Philips X-ray Spectrometer for the Department of Mineral Soils.

Mr Graham Nicol, a student at Robert Gordon's Institute of Technology, spent five months working in the Section as part of the practical part of his HND course in Electrical and Electronic Engineering.

PHOTOGRAPHY

Once again the Section has had a busy year providing photographic facilities for the Departments of the Institute.

During the year the Photographic Unit acquired a 16 mm Analytical Projector to quantify time-lapse results of kinetic growth, being studied by the Department of Soil Organic Chemistry.

A considerable number of aerial sorties were again undertaken for the Department of Peat and Forest Soils. A few of these are mentioned below:

1. The Synthetic Aperture Radar experiment (SAR 580) for the European Space Agency involving vertical and oblique photography.

2. Vertical stereo photographs in black and white and colour of the Ythan Estuary in connection with the SAR 580 experiment.

The use of 70 mm false colour infrared film was also introduced for the first time during these sorties.

JOINERY/BUILDING MAINTENANCE

This Section has been kept very busy during the past year carrying out the refurbishment of various rooms throughout the Institute.

A few examples of the wide variety of tasks undertaken by the Section are mentioned below:

Microbiology/Spectrochemistry. Alterations to Room 405 to provide laboratory space for ^{15}N analysis and for development work on a Spectral Scanning System.

Sil Fertility. Refurbishing Rooms 281D/281E, 282A, 282B and 282C to provide additional laboratory space for the Department.

Soil Organic Chemistry. Conversion of Room 110A to provide additional laboratory space for Liquid Chromatography work. Carrying out modifications to existing fume cupboard to house large Chromatography tanks and installing a new electrically heated autoclave in Room 106. Refurbishing Room 102 and installing custom-made bench units to accommodate Gas Chromatography equipment.

Peat and Forest Soils. Provision of new room under main building (access from Quadrangle) to provide sample storage and area for housing deep freeze units containing laboratory samples.

Statistics. Refurbishing Room 154 to provide separate air conditioned area for the computer mainframe and peripherals and to improve general working conditions in the user area.

11. LIBRARY

A. H. W. Dickie

The Library holds an extensive collection of literature on soil science and related subjects. The service is primarily for members of staff, but loans can be obtained by individuals and institutions, either directly or through the national inter-library lending scheme. The number of items borrowed this year increased to 860, of which 449 came from the British Library Lending Division. 134 items were lent by us to other libraries.

258 books were added to stock, but no new journals. Two Current Awareness publications are produced — a Periodicals Bulletin weekly, and a Book Bulletin monthly. Both are primarily for internal circulation, but copies are also distributed to the other Scottish Institutes and to local research establishments.

A List of Publications available appears at the end of this Annual Report. Copies of reprints and of the Lists can be obtained from the Librarian.

APPENDIX I

SIXTH

T. B. MACAULAY LECTURE

26th NOVEMBER, 1981

AMATOLA HOTEL, ABERDEEN

by

Professor DAVID J. FINNEY, F.R.S.

Chairman:

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

SIXTH T. B. MACAULAY LECTURE

Aberdeen, 26th November, 1981

AGRICULTURAL RESEARCH COUNTS

Professor DAVID J. FINNEY, F.R.S.

ARC Unit of Statistics and Department of Statistics,
University of Edinburgh

INTRODUCTION

When I read the names of previous Macaulay Lecturers, I appreciate the honour that you do me in inviting me to be one of so distinguished a group of agricultural scientists. I also cannot avoid surprise at your choice of a speaker from a discipline that is not always popular with those who work in other fields. I shall not be apologetic about the place of statistics in agricultural research: indeed my aim is to show you the essential part that statisticians play as advisers, executants, and in the fullest sense collaborators (Finney, 1972, 1978b; Snedecor & Cochran, 1980).

May I spend a moment on my credentials? My father was an accountant, his father and sisters were teachers. Most of my mother's relatives farmed in North Cheshire. At the age of 20, my own career was uncertain, but I knew that I wanted to be neither accountant nor teacher nor farmer. I have since spent 40 years as something of a mixture of the three. This period has included six years at Rothamsted, where Frank Yates taught me how statistical method could serve the needs of agricultural enquiry — something very different from using agricultural data as a vehicle for statistical theory (Yates & Finney, 1981). From 1954 to 1966, I spent a very happy spell in Aberdeen, where a major and enjoyable task was to establish the Unit of Statistics that has, I believe, become a valuable component of agricultural research in Scotland. As I look back, I realise that I have known two-thirds of the Directors of British agricultural research institutes who have ever existed, including all Directors of the Macaulay, and of course many other great personalities of agricultural science.

The study of soil, like that of other aspects of the human environment, can be justified intellectually " because it is there "; the case for large support from public funds must be upheld because soil is the medium on

which all other agricultural production ultimately depends. Two years ago, Dr Cooke gave you a masterly survey of the aims and accomplishments of that research. I shall address myself primarily to the methodology of investigation. In doing so, I shall not limit myself to problems of soils, but almost everything I say has applications within this Institute. From the earliest years of Rothamsted, emphasis was on experimentation in the field and on meticulous weighing and measuring of experimental performance. Accumulation of 75 years of records which had not been thoroughly studied was the reason for the appointment of R. A. Fisher to Rothamsted in 1919, a decision that has had immense consequence for agriculture and for other branches of science and technology. Without the revolution in outlook and method that stemmed from Fisher's many innovations, no statistician would be addressing you today.

STATISTICAL INFERENCE

The central activity for a statistician in agriculture is inference from the particular to the general. This involves the twin concepts of *population* and *sample*, distinction between which is far more evident in biology than in the pure physical sciences. If we weigh a cube of pure copper of side 1 cm, we have a result that is true for all copper everywhere, except for inaccuracies due to imperfect measuring instruments; this it not true for a similar cube cut from turnip. We cannot measure any specified property of every sheep in Scotland or of every square metre of arable soil in Aberbeenshire. We cannot measure a crop response to phosphate on every relevant site. We can measure selected sheep, analyze soil from selected small areas, conduct experiments on added phosphate at selected sites. We shall not suppose that the fleece weight of one sheep, or even the average weight of 100 fleeces, will equal exactly the mean value for all sheep, and indeed we can readily convince ourselves empirically that the idea is grossly false. Faced with the practicability of measuring a *sample* and the need to know about a population, what then can we do?

If exactness were essential, the answer would be " Nothing." In practice, the need is for a reasonable approximation, perhaps an assurance that the truth is almost certainly fairly close to a stated estimate from the sample and a recognition that any exact truth would be a fluke whose occurrence would never be known. Suppose we wish to learn about the response of barley to nitrogen in a region, with a view to making recommendations on fertilizer use. Since we cannot have advance knowledge of the responsiveness at individual sites, an ideal policy would be based on a population value, the true " mean response " for all barley land in the region. In practice, advice must be based upon the evidence from trials at a sample of sites; for this purpose, an understanding first of how repeated samples from a population behave and secondly of how the pattern of one sample can be used in making inferences about the population is essential. Expressed crudely, if the truth is unknown we can at least make good use of a numerical estimate of the truth and; associated with it, two other values representing the highest and the lowest that are plausible for the

truth in the light of the observed variability in the data. Our recommendations will not be correct in every instance, any more than the prescriptions of a good physician are ideal for every patient, but they will employ all available information and will scarcely be bettered without more intensive collection of data.

This in simple form is the basic problem of inference by estimation, the step from the particular to the general. In my view, it subsumes other aspects of statistics, such as significance tests and decision theory; even the descriptive procedures concerned with presentation must serve the ends of estimation.

SAMPLING

The simple class of problem that I have mentioned arises often. Whether one studies a chemical property of a soil, the prevalence of a plant pest or disease, the quality of milk, or the educational backgrounds of farmers, sampling is essential. As is intuitively obvious, the quality of estimation is affected by how the sample is selected. Other things being equal, the larger the sample the more precise will be the estimate based upon it. Size alone is not enough. The definition of the sampling unit — a small area of land, a single plant or a leaf, a farm — and how units from the population are selected for the sample are vitally important. These factors affect both the validity of any estimate, in respect of freedom from bias, and the precision. By random selection of units from among all that make up a population, freedom from inherent bias is ensured. Bias is not necessarily a consequence of intentional dishonesty; the consequences may be just as serious if, say, subjective judgement is used to select " typical " plants, for almost inevitably this will produce unsuspected departures from the true representativeness that random selection would give.

Good sampling for any property of a population calls for five features:

(i) Careful definition of sampling unit;

(ii) Controlled design, usually in the form of *stratification*, or subdivision of the population into distinct strata with insistence that every stratum shall be represented by sampling units in the final sample;

(iii) Replication, or inclusion of at least two units from each stratum so that sampling variation can be estimated;

(iv) Random selection of units from all possibilities permitted by the design;

(v) Precision, achieved by (i)-(iv) in combination with a total size of sample adequate for the purpose in hand.

All these involve statistical considerations (Cochran, 1977). Only in random selection is there an unequivocal requirement. The others call for judgement based upon knowledge of the material sampled, statistical principles, and empirical evidence of the variability encountered and recorded in previous sampling of similar material. Seldom is there one

obviously best plan: the choice made should arise from interaction between a statistician and the scientist concerned with the purpose of sampling.

The basic principles have been applied to give rigorous yet convenient sampling methods for many purposes — studying individual plots for incidence of pests and diseases, examining the chemical composition of plants (both during growth and after harvest), estimating natural insect populations, and in laboratory work. During the war, assessment of crop danger from pests, particularly wireworm, by extensive sampling of many fields proved valuable to the advisory services (Finney, 1941; Yates & Finney, 1942; Anon, 1944). Techniques using recaptures of marked individual animals or insects, a complex and specialised topic, have been developed to a stage of practical utility (Seber, 1973; Cormack, 1979); they will prove valuable for assessing changes in natural populations of harmful and beneficial species.

SAMPLE SURVEY

Some sampling studies seek to estimate only a single property, even though the operation is repeated on many populations — different plants, different fields, different animals, or at different times for the same individual. There are special problems in planning such series of samples, especially when a time sequence is envisaged, but I shall not discuss these. Another type of complexity enters when many distinct records can be made on each sampling unit.

For example, the sampling unit may be a farm. From the population of farms within a region, a random sample may be chosen. Even if the initial objective is to obtain information on one characteristic of each farm — perhaps the expenditure on fertilizers in 1980, or the number of breeding ewes — once contact has been made with the farmer a little extra effort may produce answers to a range of questions about the pattern of farming. These might include information on areas under different crops, varieties of seed, quantities of fertilizer, use of pesticides, livestock management practices, buildings and equipment, and so on. Such an enquiry would constitute a sample survey. Obviously planning the selection of farms now involves compromise among what appears to be best for the many separate questions, and in respect of precision the sampling cannot be ideal on every question. The compensation is that a good survey permits formation of a broad picture of some aspects of agriculture in a region: as well as separate variates, relations between variates can be studied. In practice, one would scarcely opt for a sample survey quite as broad as I have outlined. Any survey involves a battery of questions and the willing co-operation of those who must answer is likely to be reduced by a very long questionnaire. Thus policy will usually dictate that the questions be directed at a restricted number of related themes, with some built-in cross-checking to ensure consistency and to guard against accidentally or wilfully misleading responses. Biased answers are a hazard requiring careful attention at the stage of wording the questions, especially on moral, financial, or other

sensitive issues. Ambiguity of phrasing may permit double counting (e.g. grassland that is both cut and grazed in the same year) or omissions (e.g. unusual crops or items of various kinds needing to be trapped by a heading such as "Other — please specify"); inexact definitions may encourage bias from personal judgement.

The planning of a sample survey, in agriculture or in any other context, calls for good collaboration between experts in the subject matter and experienced statisticians. Either alone is liable to make gross errors, and only the closest interaction will suffice to produce questions that facilitate willing, bias-free answers. Although responsibility for collecting data rests largely with those skilled in the subject matter, reduction of individual returns to tables and diagrams that summarize adequately the information collected is primarily a task for statisticians; fortunately computer programs (such as RGSP) now ease the labour and make possible a detailed examination that was scarcely conceivable 30 years ago. Production of a critical and comprehensive report again demands the fullest co-operation between all involved in planning, execution, and analysis. Survey practice in agriculture was pioneered from Rothamsted, especially in surveys of practice in fertilizer use (Yates, 1981). In 1942, in order to see how effectively farmers were using limited fertilizer supplies, a small survey was conducted in three contrasting regions. For each crop grown on a sampled farm, details of fertilizers actually applied were obtained for one old arable field and one newly ploughed-out from grass; soil samples were taken from a sub-sample of fields. The useful information that emerged proved to the advisory services that quite small but well-designed surveys were essential tools in ascertaining the true extent of local problems. Rothamsted fertilizer surveys have continued ever since. We in Scotland conducted similar surveys for 10 years (Rutherford & Symon, 1960): were we wise to stop 15 years ago? Other successful applications of survey technique have related to animal health, cereal diseases, crofting, pesticide use, weed distribution, to name only a few.

TABLE 1

Estimated percentages of grassland in England and Wales receiving different amounts of nitrogen in 1980

Utilization	% of total grass area	Nitrogen (kg/ha) 0	1-100	100-199	200-299	300-399	400-
Grazed intensively	14	9	24	23	18	18	7
Grazed intensively and cut	7	3	21	38	22	13	3
Cut for silage	14	2	15	38	25	16	4
Cut for hay	21	13	54	27	4	2	0
Other grazing	44	34	37	21	5	3	0
All	100	20	34	26	11	7	2

Reproduced by kind permission from Church and Leech (1981).

Table 1 illustrates the kind of information obtainable from sample surveys (and, reliably, in no other way). Taken from the report on fertilizer surveys in England and Wales for 1980, it shows the diversity of usage of nitrogen on grassland and the very marked differences in pattern according to the manner in which the grass is utilized. Although qualitatively the picture may be as expected, there are obvious merits in having quantitative statements that can be compared from year to year to show trends. Of course similar information is available for phosphate and potash, and the data could be subdivided according to region.

EXPERIMENTATION

A sample survey tells of things as they are, so giving information valuable to those who provide advisory services. I cannot emphasise too strongly that it does not produce estimates of the effects of change. Argument often arises over the collection of yield records as part of a survey of agricultural practice. The information may be useful, but any assumption that a difference in mean yields of potatoes between farms using different fertilizer dressings can estimate the effects of fertilizer is naive in the extreme. There is no reason to suppose the farms comparable in other respects: the heavier users of fertilizer may be those who have better soils, who grow varieties that respond well to fertilizers, who operate pest control more effectively, who are in other respects the better farmers. Suggestions that procedures variously described as operational research or analysis of systems can overcome this difficulty are gravely misleading.

Only well planned experiments that compare treatments under fair conditions can measure effects of differences in fertilizer and other treatments. The requirements are analogous to those for sampling — stratification of plots into reasonably homogeneous blocks, definition of a set of treatments appropriate to exploration of the subject in hand, randomization of the order of treatments within blocks, and replication sufficient for the desired precision of estimating effects (Cochran & Cox, 1966; Cox, 1959; Fisher, 1966).

One of R. A. Fisher's most inspired and far-reaching contributions to experimental design was his recognition that assigning treatments at random to the plots (subject to the constraints of blocks) would ensure that all treatments had an equal chance of being favoured by the luck of the draw, and that the estimate of error variance provided by the analysis of variance would be unbiased whatever the distribution of the actual errors. (This is *not* achieved by a "haphazard" allocation affected by unknowable subjective biases, but requires operation of a rigorously fair lottery or an equivalent process). Initially the necessity for and effectiveness of *randomization* were hotly disputed: as understanding of experimental design grew, randomization became the norm for sound research. The merits are not restricted to field plot trials, but apply equally to animal and to laboratory experiments. Certainly in some types of investigation randomization is impracticable, but any scientist who does not randomize

the allocation of experimental material to treatments needs to discuss carefully the likely consequences for validity of his inferences. The need is now recognised far beyond agriculture: clinical medical research has improved immeasurably as a result of proper appreciation of the role of randomization, as also has research in industrial technology.

Another major contribution by Fisher to experimentation was explicit recognition of *factorial design* and its elaboration to meet many needs, especially (but not only) for fertilizer and other field plot research. Inclusion of all combinations of several variants of two or more factors in one experiment is clearly necessary to determine whether the effect of one factor depends upon the state of another: even when such interactions are believed to be unimportant, the fact that each plot contributes information on the effects of several factors leads to considerable gains in efficiency and ensures a wider inductive basis for inferences from the results. The main limitation to factorial design in field experiments is that, if many factors are included, the number of treatment combinations requires many plots. Complete randomized blocks will be large and relatively ineffective in removing the variability in the experimental material. Fisher early perceived that each replicate could be split into smaller blocks in such a manner that the contrasts between the blocks corresponded to chosen experimental contrasts, usually components of unimportant high-order interactions. This device he termed *confounding*. In the 1930s, further development permitted use of only one replicate, experimental error being estimated from the unconfounded components of high-order interactions. For example, a single replicate of a 3 x 3 x 3 experiment on three levels of each of three factors can be arranged in 3 blocks of 9 plots, with each block containing all 9 combinations of each pair of factors. This gives nine replicates for the main effect of each factor and three replicates for each two-factor interaction (Yates, 1937). When there are many factors, a further extension is to include only a balanced selection from all possible combinations; this is termed *fractional replication* (Finney, 1945).

Tables 2 - 5 illustrate the steadily increasing complexity of these ideas, as applied to a situation in which blocks should not exceed 8 plots each. Table 2 shows how a simple experiment on the three main fertilizer elements in all combinations of absence and presence, a 2^3 (or 2 x 2 x 2) factorial, can be conducted in randomized blocks, each of four blocks including the same eight treatment combinations in orders that will differ after randomization. Table 3 includes an extra factor, depth of ploughing; the 16 treatments of the 2^4 factorial are now confounded between pairs of blocks in such a way that all interesting comparisons are balanced in respect of block differences and only the rather uninteresting interaction of all four factors is lost. The idea is extended in Table 4. Here two varieties of crop are included, and the 2^5 factorial is confounded into a single replicate of four blocks; each combination of factors appears only once, but average effects of all factors and simple interactions are still well estimated, and the interactions lost by confounding are of little interest. Table 5 is somewhat extreme, though the idea can be exploited very successfully in larger experiments of, say,

TABLE 2

Contents of blocks for 2^3 factorial in four replicate blocks

Block	Treatments (to be randomized within blocks)			
I	$N_0P_0K_0$ $N_1P_0K_0$	$N_0P_0K_1$ $N_1P_0K_1$	$N_0P_1K_0$ $N_1P_1K_0$	$N_0P_1K_1$ $N_1P_1K_1$
II	Same as Block I			
III	Same as Block I			
IV	Same as Block I			

N_0, N_1 : plots without and with nitrogen

P_0, P_1 : plots without and with phosphate

K_0, K_1 : plots without and with potash

TABLE 3

Contents of blocks for two replicates of 2^4 factorial confounded in four blocks

Block	Treatments (to be randomized within blocks)			
I	$N_0P_0K_0D_0$ $N_1P_0K_0D_1$	$N_0P_0K_1D_1$ $N_1P_0K_1D_0$	$N_0P_1K_0D_1$ $N_1P_1K_0D_0$	$N_0P_1K_1D_0$ $N_1P_1K_1D_1$
II	$N_0P_0K_0D_1$ $N_1P_0K_0D_0$	$N_0P_0K_1D_0$ $N_1P_0K_1D_1$	$N_0P_1K_0D_0$ $N_1P_1K_0D_1$	$N_0P_1K_1D_1$ $N_1P_1K_1D_0$
III	Same as Block I			
IV	Same as Block II			

D_0, D_1 : shallow and deep ploughing

Other treatments as in Table 2

TABLE 4

Contents of blocks for single replicate of 2^5 factorial confounded in four blocks

Block	Treatments (to be randomized within blocks)			
I	$N_0P_0K_0D_0V_0$ $N_1P_0K_0D_1V_1$	$N_0P_0K_1D_1V_1$ $N_1P_0K_1D_0V_0$	$N_0P_1K_0D_1V_0$ $N_1P_1K_0D_0V_1$	$N_0P_1K_1D_0V_1$ $N_1P_1K_1D_1V_0$
II	$N_0P_0K_0D_1V_0$ $N_1P_0K_0D_0V_1$	$N_0P_0K_1D_0V_1$ $N_1P_0K_1D_1V_0$	$N_0P_1K_0D_0V_0$ $N_1P_1K_0D_1V_1$	$N_0P_1K_1D_1V_1$ $N_1P_1K_1D_0V_0$
III	$N_0P_0K_0D_0V_1$ $N_1P_0K_0D_1V_0$	$N_0P_0K_1D_1V_0$ $N_1P_0K_1D_0V_1$	$N_0P_1K_0D_1V_1$ $N_1P_1K_0D_0V_0$	$N_0P_1K_1D_0V_0$ $N_1P_1K_1D_1V_1$
IV	$N_0P_0K_0D_1V_1$ $N_1P_0K_0D_0V_0$	$N_0P_0K_1D_0V_0$ $N_1P_0K_1D_1V_1$	$N_0P_1K_0D_0V_1$ $N_1P_1K_0D_1V_0$	$N_0P_1K_1D_1V_0$ $N_1P_1K_1D_0V_1$

V_0, V_1 : two varieties

Other treatments as in Table 3

TABLE 5

Contents of blocks for half-replicate of 2^6 factorial confounded in four blocks

Block	Treatments (to be randomized within blocks)			
I	$N_0P_0K_0D_0V_0T_0$	$N_0P_0K_1D_1V_0T_0$	$N_0P_1K_0D_1V_1T_1$	$N_0P_1K_1D_0V_1T_1$
	$N_1P_0K_0D_1V_1T_1$	$N_1P_0K_1D_0V_1T_1$	$N_1P_1K_0D_0V_0T_0$	$N_1P_1K_1D_1V_0T_0$
II	$N_0P_0K_0D_1V_1T_0$	$N_0P_0K_1D_0V_1T_0$	$N_0P_1K_0D_0V_0T_1$	$N_0P_1K_1D_1V_0T_1$
	$N_1P_0K_0D_0V_0T_1$	$N_1P_0K_1D_1V_0T_1$	$N_1P_1K_0D_1V_1T_0$	$N_1P_1K_1D_0V_1T_0$
III	$N_0P_0K_0D_0V_1T_1$	$N_0P_0K_1D_1V_1T_1$	$N_0P_1K_0D_1V_0T_0$	$N_0P_1K_1D_0V_0T_0$
	$N_1P_0K_0D_1V_0T_0$	$N_1P_0K_1D_0V_0T_0$	$N_1P_1K_0D_0V_1T_1$	$N_1P_1K_1D_1V_1T_1$
IV	$N_0P_0K_0D_1V_0T_1$	$N_0P_0K_1D_0V_0T_1$	$N_0P_1K_0D_0V_1T_0$	$N_0P_1K_1D_1V_1T_0$
	$N_1P_0K_0D_0V_1T_0$	$N_1P_0K_1D_1V_1T_0$	$N_1P_1K_0D_1V_0T_1$	$N_1P_1K_1D_0V_0T_1$

T_0, T_1: early and late sowing

Other treatments as in Table 4

64 or 128 plots. A sixth factor, sowing date, is added, and the experiment now includes only 32 of the possible 64 ($=2^6$) combinations; the half-replicate is chosen in such a way as to lose relatively little information. Similar tricks can be played with factors at three levels, though the designs then look much more complicated.

The same principles of design apply to research on farm animals or in the laboratory. The need to study repeated measurements on the same animal (as in research on nutrition, growth, milk production, etc.) introduces some major differences of practice, for example because there may be complex carry-over effects between pregnancy and lactation or effects of treating parents may appear and be measured in progeny. By comparison with plants, there is greater emphasis on relations between measurements of different characters at one time and of one character at many times, relations that are often non-linear and of a complexity seldom handled before computers were available. Some important research involves continuous monitoring of individuals and their environments, often with the aid of sensors and recording devices. Whether for body weight or for more sophisticated study of physiological variable, analysis of such records cannot ignore the correlation between successive times.

In 1953, when addressing the British Association, the distinguished astronomer and geophysicist Sir Harold Jeffreys said "... the standard of presentation of results in agriculture is better than in any of the so-called exact sciences." He was undoubtedly thinking largely of the standards of planned experimentation. I could talk for long about the ramifications of experimental design and their practical application, but I shall limit myself to one aspect where much yet remains to be done.

SELECTION AND TESTING OF CROP VARIETIES

The ability to do large and complex field experiments of high precision has had some unfortunate effects, not least in fostering the illusion that complicated issues could be settled once and for all by a single experiment at some research institute. In reality, conclusions from such an experiment need testing under a wide range of soil and meteorological conditions before they can safely form the basis of practical recommendations to farmers. The most effective way of doing this is by means of a co-ordinated series of field trials, all of similar or identical design, widely dispersed and extending over several years.

Plant breeding and varietal improvement illustrate this well. Riley (1981) mentions that selection for winter wheat at the Plant Breeding Institute involves annually about half a million new second generation derivatives from experimental hybridizations; six years later, possibly only two or three will survive for inclusion with similar selections from other sources in final performance tests. This rapid reduction in numbers, achieved by annual trials and subsequent rejections, offers much scope for varied practices. Should selection in the first year or two be intensive so that the later years can look more thoroughly at a moderate number, or should the early selection be slower so as to reduce the chance that a good variety is rejected before it has been adequately tested? Is a period of six years right for the process? Many years ago (Finney, 1958a, b), I studied a formalized problem based on these questions. I concluded that (under stable conditions) a constant rate of selection in every year, combined with equal division of resources between the annual stages, would be nearly optimal; for the wheat selection above, this would represent retaining 10%-15% from each year to the next. The rule is not universal, but the approach can readily be adapted to other formulations and modern computer power can facilitate otherwise laborious analyses. I mention this work simply to emphasize that specification of the overall fraction to be selected, the resources (land, labour, time) available, and the pattern of variability for any criterion on which selection is to be based, enables a statistician to make a sensible contribution to selection policy. The manner of formulating the problem was more important than any particular results.

When a very few varieties have been chosen from each of several distinct streams of breeding and selection, all must be compared with current standard varieties. This has always been desirable; today, under EEC regulations, a systematic testing of new varieties is mandatory before commercial release can be permitted. Each variety needs to be included in a co-ordinated series of trials, distributed over a number of sites in at least three successive years, so as to take account of the possibility that relative performance varies with locality or season. Despite the effort they have expended on combinatorial theory of design for individual experiments, statisticians have done rather little to develop plans for series of experiments. For more than 10 years, my colleague Dr Patterson has been concerned with this topic, especially for variety trials. He has devised a new class of incomplete block designs to meet the requirements of comparing

any number of varieties (Patterson *et al.*, 1978). He and his colleagues have constructed a computer-based system, CVT, that handles the complete data from national trials; details of design for each trial are produced and distributed, all records relating to trials are filed and monitored as received, statistical analyses and summary tables for each trial are produced as soon as the data are available, and up-to-date summaries for any series can be produced at any time (Patterson and Silvey, 1980). In this way, all queries about records can be handled expeditiously. Within days of the last harvest, summary tables for the whole series are available for those who must plan the next year's programme, a feature that is especially important for any crop that must be sown soon after the previous harvest. Research is proceeding on improved techniques of interpreting evidence on interactions of varietal differences with place and year. Much remains to be done, but my colleagues have created a total system that attempts to use statistical and computing skills optimally for planning, recording, and interpreting series of experiments.

Improvement of varieties of any major crop is a continuing and apparently endless need. The procedures adopted therefore should provide for evolution towards economy and efficiency. Not only must the best designs for individual trials be found, but the number of trials per year and the number of years over which each variety is tested must be optimized. These are not solely matters of statistical theory; they involve empirical information and appreciation of questions of agricultural practice and policy. A scheme that is good for winter wheat in the UK is not necessarily ideal for potatoes or even for barley, and almost certainly will need change for rice in Indonesia. The CVT system permits estimation of variance parameters that can be used to assess the minimal replication in sites and years that is consistent with adequate precision in varietal comparisons. It has contributed to economy in the use of resources for UK trials, and has been exported to research organizations overseas. Moreover, it contains much that can be adapted to the needs of series of agricultural experiments for other purposes.

ESTIMATION AND PREDICTION

I have spent much time talking about two branches of statistics that have long played major roles in agricultural research. Please note that I have not mentioned what too many scientists regard as the chief objectives of statistical analysis, namely tests of significance. These have their uses, but they are seldom of primary importance — least of all in sample survey or variety testing. Statisticians today rightly place greater emphasis on the closely related aims of estimation and prediction, for example *estimating* the numerical properties of a population from records made for a sample and *predicting* the future performance of a variety from experiments that are now complete.

Let me comment briefly on three other illustrations. *Biological assay* is concerned with using measured responses of biological material to an applied stimulus in order to estimate the relative potency of alternative

forms of stimuli (Finney, 1978c). The techniques have been used particularly in standardizing batches of drugs for medical purposes, but applications to insecticides and other pesticides have been numerous. If under controlled conditions either 5 ml of insecticide A or 1 ml of a standard insecticide will kill, say, 40% of insects under test, there is some basis for stating that A has a potency of 0·2 relative to the standard; if also 15 ml of A and 3 ml of the standard both kill 85%, the argument is strengthened. The statistical problems relate to how best to estimate this potency from experimental results at several doses of each insecticide, and how to plan experiments that will use time and insect stocks well. More recently, radioimmuno– and other immunoassay techniques that have many points of logical similarity have become important, for example for estimating hormone status in individual animals. Methods of computation are very different, but again the emphasis is on estimating a parameter, the true relative potency, from results of a particular experiment. Another application concerns the need to calibrate an instrument for future use, by reference to a set of comparable measurements made with it and with an alternative instrument that is known to be very accurate. The process of constructing a calibration curve or table is logically very similar to the analysis of bioassays.

Many types of investigation produce *multivariate data,* that is to say records of individuals each of which has been measured or classified in respect of a set of characteristics. One interesting form of analysis consists in seeking " clusters " of records that may be meaningful. If k characters have been measured on each individual, they can be regarded as co-ordinates of a point in k-dimensional space ($k=2$ and $k=3$ are easily visualized): does the set of points display a patternless scatter or does it have a number of more concentrated clusters? The question seeks to explore the data and to generate ideas on classifications rather than to produce a definitive interpretation. There are many variants of the procedure, but all use solely the internal structure of the data to suggest clusters, after which the user of the technique will inquire into the possibility that these correspond with real properties of the material studied (Cormack, 1971). Even with modern computing power, the method can be laborious; far more experience of it is needed, but it has been exploited for various agricultural purposes, such as examining evidence that crop varieties are distinguishable. Cluster analysis is related to the older and better understood discriminant analysis, which makes use of a sample known to be correctly classified and develops rules for dealing consistently with other observations. Discriminant analysis itself has been employed effectively in problems of soil classification (Henderson and Ragg, 1980).

My third illustration concerns *growth studies,* an important topic in animal and plant research (Kowalski & Guire, 1974; Finney, 1978a). Provided that a measurement does not involve destruction of an animal, it can be repeated at intervals. Thus a sequence of, for example, body weights in the life of one animal is obtained. Analysis of data in a time sequence must distinguish between measurements that refer to a different animal

each time (as would be necessary, for example, in a study of weight of dressed carcass) and those that are repeated on the same animal. Repeated measurements should yield much more precise estimation of parameters of growth but the need to take account of autocorrelations complicates the statistical analysis very considerably, especially if time intervals are unequal. Progress is being made, slowly, in stochastic process theory that will permit satisfactory estimation without forcing so much attention to be given to each animal that resources are inadequate for replication of animals; the non-stationarity of the relevant processes creates major difficulties (Glasbey, 1979).

In all my examples, emphasis lies on reduction of sets of observations to a few numbers that convey the essence, estimates of parameters that describe the main characteristics of the system after allowance for all sources of inherent variability. Such estimates may be wanted primarily for good descriptive summaries (in sample surveys), for aiding decisions on policy and practice (should a new fertilizer or a new variety be recommended?), or for a synthesis of information that can predict future behaviour (how satisfactorily can the effects of a new pesticide be predicted? What can be said of the likely consequences for animal growth of a change in conditions or an alteration in a parameter?).

MODELS

In recent years, " model " has become one of the most overused words in biometry. There are statisticians who cannot use a Normal distribution without reference to " the Normal model," and analysis of variance is commonly described in terms of " linear models." At the other extreme, some research organizations encourage " modelling " as an activity to be contrasted with statistics. This usually implies removal of much or all of the probabilistic content by assuming values for parameters to be known. Emphasis can then be put on seeking a set of equations to represent plant growth or the physiological processes associated with milk production, into which " known " parameters can be inserted to give determinate answers. Either usage can be absurd. No experienced statistician could believe that the mean effect of fertilizers on potatoes is exactly expressed by simple additions of a few parameters termed " main effects " and " interactions "; estimates of such parameters may be very satisfactory in a summary of experiments and as a basis for recommendation, but to speak of them as constituting a model of fertilizer responses is a misleading use of words. No thoughtful biologist could believe that a few mathematical equations exactly represent milk production in cows, without even allowance for inherent unexplained variability, yet study of such deterministic equations may be useful in suggesting further lines of research.

Physical science abounds in models that can claim to be good quantitative approximations of great generality. Newton's gravitational theory may not be seen today as exact, but it is sufficiently close to the truth to be of wide applicability. As yet, biology has few comparable laws. The simple rules of genetic segregation have the same quality of generality, and in

association with multinomial probability distributions may reasonably be termed mathematico-statistical models of a biological process. But to regard every mathematical formula used in a statistical analysis as a model is a regrettable practice that can engender misunderstanding of the nature of statistics. Still more dangerous is the neglect of biological diversity implied in a process of model building that arbitrarily assumes numerical values for parameters and ignores the variance structure in the population. Emphasis on the study of a model too often concentrates attention on the nature of the model itself and how best to estimate the remaining unknown parameters, when the important questions are really those relating to whether the model corresponds well to the real world. In extreme instances, study of a model can be so seductive that a scientist's affections are totally alienated from measurement of biological reality.

I hope I shall not be misunderstood on what I consider one of my most important topics this afternoon. Advance in scientific understanding in any field will often involve increasingly mathematical representation of interrelations; development of realistic mathematical models, with full testing of their adequacy and estimation of all parameters, is very desirable but not easily achieved. My concern is that too ready a use of the word "model" debases our linguistic currency, and delays progress because it allows practical convenience and operational utility to masquerade as general scientific truth.

COMPUTATION

My title suggests that I should comment explicitly on computation. I hope my conviction that well-organized computation forms an integral part of good statistical practice is already evident. Statistics is not a branch of mathematics; it is a science that builds extensively on mathematical theory, that also uses models of thought from outside mathematics, that requires understanding of a field of application, and that is implemented through arithmetical techniques. Fisher and all who followed him in agricultural statistics have been very conscious not only of the necessity of computation for the interpretation of data but also of the part that doing arithmetic plays in teaching about the nature of statistical analysis.

The programmable computer has brought a revolution in what is computationally practicable. One important consequence is that complicated analyses can be undertaken by scientists with little knowledge of statistical method. The amount of statistical computing required in agriculture far exceeds what can be directly supervised by statisticians. Therefore, the training of agricultural scientists must enable them to recognize the essential statistical characteristics of their data and to choose programs appropriate to tasks; this today is more important than earlier practices of teaching the details of executing analyses on desk calculators, although some exposure to such processes remains part of the best way of learning how to handle data. Though many good programs for analyzing experimental data exist (GENSTAT and others), these may be less suitable for

other users than for professional statisticians. The fact that a particular program will accept a set of data is no guarantee of the program's appropriateness: gross errors may result from neglecting the discreteness of data, ignoring design constraints, failing to note variance heterogeneity, and so on, and good knowledge of possibilities is needed for gain in precision from covariance analysis or wise choice of regression functions. Statisticians need to develop software that incorporates safeguards against misuse, and that by good documentation and interactive or conversational operation assists the scientist in every possible way. Too often those who develop statistical software neglect aspects of input and output that are tedious to prepare yet important to the non-professional user. Unless the rules for input are devised to suit the manner in which data are acquired, an otherwise good program may be used wrongly or neglected. Unless the output is planned with great care, the user may be left with the need to prepare supplementary tables by hand, or a flood of tables and diagrams may distract his attention from what is most important.

Not only can long-familiar calculations now be completed more speedily: new computations become practicable and new ways of examining data can be tried. Recent years have seen immense growth of graphical techniques for exploiting bodies of data with a view to generating ideas on interpretation. These can be used to excess, and may encourage neglect of well-designed experiments, but as experience leads to a sound code of practice they should be increasingly valuable. Multivariate analysis can be overused, but computers enable alternative techniques to be compared operationally, in terms of the labour involved and the quality of data-interpretation that results. In regression analysis, we are no longer tied to the classical linear and polynomial equations, but can now formulate problems in terms of parameters more sensibly related to biological reality. Simulation techniques are invaluable in the solution of problems that are mathematically intractable. The database concept is already proving its importance for soil scientists, among others. Without the computer there could be no possibility of amassing large bodies of quantitative and qualitative data into files that can be frequently updated and interrogated at will in respect of any relevant characteristic.

Forty years ago, one could buy an electromechanical calculator for £200-£400, approximately my annual salary at the time. Today, less than 1% of the salary of a comparably inexperienced scientific officer will buy a pocket calculator that in every respect — speed, power, range of facilities, reliability — is far superior. For 10%-20% of that salary, he can have on his desk a microcomputer that must be rated as at least 100 times as effective. How should statistical practice respond to the possibilities of such equipment being available to most agricultural scientists who need statistical analyses? My belief is that at present these micros should be seen as invaluable tools for exploratory computation, statistical and other, but should not be used extensively for definitive statistical analyses. I see little reason for spending scarce human resources on the programming effort

needed to adapt software of reasonable generality to the restricted store and other facilities of the present generation of micros; much ingenuity would be needed and many desirable features would be sacrificed in programs for computers ill-suited to input of substantial amounts of data, yet most potential users can also have access to larger computers already well equipped with software. I do not think statisticians will be prepared to undertake this programming. Undoubtedly other users will write simple regression and analysis of variance programs as exercises in learning to use a micro, but immense wastage of time will occur if this leads to proliferation of programs (often not of the highest quality) within institutes. I might think differently on this issue if I were working in a developing country with many micros available but access to a mainframe computer difficult or unreliable. A new generation of micros, with larger stores and other improved facilities, however, seems likely to alter the picture, especially when these can also act as intelligent terminals to a mainframe.

COLLECTION AND PRESENTATION

I have talked of the planning of quantitative research and of principles and practice underlying statistical analysis of results. Two other phases are vitally important and should exercise the statistician considerably, but my remarks today must be brief.

All data require collection and transfer to the process of analysis. This may entail the writing of measurements as they are made in the field, the operation of hand-held electronic recording devices followed by transfer to computer files, or reading files from automatic data-logging equipment. Whatever is used, careful advance planning of format, with attention first to convenience and reliability in the field and secondly to quick and accurate entry into statistical analysis of whatever kind is deemed appropriate. The statistician is entitled to a say in something that is later to concern him deeply; his colleagues will be unwise if they do not welcome his co-operation in ensuring efficiency and inserting adequate internal checks for the records that are the primary product of an investigation.

After statistical analysis is complete and all aspects of interpretation have been fully discussed among collaborators, the results must be presented in a report or scientific paper. Tables and diagrams should be clear summaries of information, pointing to or emphasizing the main conclusions. They can be cluttered with irrelevant and superfluous detail or misleading by reason of biases and distortions. The construction of tables and diagrams will usually, but not invariably, devolve upon the statistician; their factual correctness and their effectiveness as vehicles of information needs to be monitored by all parties to the research. This task is too often regarded as a simple minor aspect of report writing. Huff (1973) gives a very readable account of how to fall into the many pits that await the unwary. If these are avoided, many positive steps remain to be taken in order to achieve a presentation that is correct, intelligible, and attractive to the reader.

THE ROLE OF STATISTICIANS AND THE ETHICS OF STATISTICS

The advance of scientific agriculture calls for effort in many disciplines, often with co-operation between different specializations within a single research project. Though I speak as a statistician, nothing I have said implies belief in the primacy of statistics. I am very conscious of the need for partnership, and I am insistent that a statistician who is properly involved in a project must be a true partner. His expertise is that of handling quantitative problems relating to data subject to biological variability (Finney, 1956, 1974, 1978b). I have commented on the need for other agricultural scientists to have some knowledge of statistical principles: equally, the statistician must learn enough of other disciplines to be able to express his more abstract ideas in practical terms, to talk and write coherently about real problems of soils, plants and animals rather than about purely mathematical entities, and to communicate with colleagues in a way that deserves respect. He should be involved in all stages of research (Finney, 1981). He can contribute to the early planning, by advising on optimal deployment of resources and on exact definition of measurements and observations. This precedes the more formal combinatorial aspects of designing an experiment or other investigation. He should certainly see something of field and laboratory operations, both to give him a sense of what is practicable and to let him see where variability and bias may enter. He will be concerned with the manner of recording data and of course will be responsible for managing statistical analyses. He fails in his duties if he does not contribute to interpreting results and drafting appropriate parts of reports; when he so contributes, his colleagues will be at fault if they do not recognize his place as one among the authors of publications. Moreover, he needs to recognize that human resources will never suffice for statisticians to participate fully in every piece of quantitative research, and that therefore he has a duty to assist his colleagues to better understanding of statistical work they can undertake themselves.

Medical research was much later than agricultural in seeing the need for statistical science, but the last 30 years have brought great changes. Not least important and interesting is the relation with ethics. Concern for individual patients brings increasing realization that as few patients as possible should be exposed to the discomforts and uncertainties inherent in much clinical investigation, and that all relevant research information must be evaluated optimally. To a substantial extent, though by no means wholly, these are matters for statisticians.

We are all potential patients, and are therefore all concerned with the ethics of medical research and patient care. We are also all in various ways taxpayers financing agricultural research; many of us in addition feel a concern for the welfare of animals and for protection of our biological environment. May I leave you with the thought that good experimental planning, a scale of experimentation appropriate to the quality and precision desired in the conclusions, optimal analysis and evaluation of results, and

care for economic deployment of resources of all kinds are for us also ethically imperative? Too long and too often, whether or not a programme of research should have adequate statistical support has been regarded by some senior scientists as little more than a matter of personal inclination.

Agricultural research *counts*, and in the broadest sense must count and figure wisely. A major piece of research in agriculture or animal husbandry that is to depend upon quantitative assessment of results requires the full involvement of a statistician, or of one of those rare but excellent scientists who have added broad statistical understanding to professional qualifications in another field; I assert uncompromisingly that without this involvement such research is improperly conceived and almost certainly ill-executed.

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APPENDIX II

VISITS ABROAD — 1980-81

	Place/Event	*Lectures*	*Date*	*Financed by*
H. A. Anderson	Reims (France) Colloquium on Humus Nitrogen	1	July	DAFS
B. W. Bache	Warsaw (Poland) 16th Intern. Potash Inst. Colloq. Agr. Yield	—	June	DAFS
J. R. Bacon	Helsinki (Finland) EUROANALYSIS IV Conference	1	August	Self
D. C. Bain	Bologna/Pavia (Italy) 7th Intern. Clay Conference	—	September	DAFS
T. E. Edmonds	Helsinki (Finland) EUROANALYSIS IV Conference	1	August	DAFS
V. C. Farmer	Bologna/Pavia (Italy) 7th Intern. Clay Conference	1	September	Clay Minerals Group
B. A. Goodman	Bologna/Pavia (Italy) 7th Intern. Clay Conference	3	September	DAFS
B. A. Goodman	Geneva (Switzerland) University	1	September	Geneva Univ.
R. Grant	Wageningen, Amsterdam (The Netherlands) Universities	—	May	DAFS
P. D. Hulme	Oulu (Finland) University Field Stations	1	July/August	DAFS
R. C. Mackenzie	Bologna/Pavia (Italy) 7th Intern. Clay Conference	2	September	Clay Minerals Group
H. G. Miller	Canberra (Australia) CSIRO Forest Nutrition Workshop	2	August	CSIRO
H. G. Miller	Kyoto (Japan) XVII IUFRO Congress	1	September	DAFS
E. Paterson	Bologna/Pavia (Italy) 7th Intern. Clay Conference	2	September	DAFS
P. F. S. Ritchie	Heerburg (Switzerland) Wild (Heerburg) Ltd.	—	April	Wild (UK) & (Heerburg)
R. A. Robertson	Tallin (USSR) International Peat Society	—	October	Self
R. A. Robertson	Finland — Study Tour of Peat Industry	—	August	Self
R. A. Robertson	Wageningen (The Netherlands) Council of Int. Peat Society and Symposium	—	August	DAFS
R. A. Robertson	As (Norway) Int. Peat Society Working Group on Standards	—	September	Conference Organisers
R. A. Robertson	Thunder Bay, Winnipeg (Canada) Bemidji (USA) Symposia on Peat and Environmental Studies	1	October	Ministry of Energy (Canada)
J. D. Russell	Bologna/Pavia (Italy) 7th Intern. Clay Conference	—	September	DAFS
R. O. Scott	Louvain (Belgium) IUPAC General Assembly	—	August	DAFS
B. L. Sharp	Tokyo (Japan) XXII Colloq. Spectroscop. Int.	1	September	DAFS
G. C. Stove	Varesse (Italy) SAR 580 Exp. Workshop/Ispra	—	February	European Space Agency
G. C. Stove	Heerburg (Switzerland) Wild (Heerburg) Ltd.	—	April	Wild (UK) and (Heerburg)
A. M. Ure	Cork (Ireland) Symp. Analtyical Chemistry	1	December	Cork Univ.

	Place/Event	*Lectures*	*Date*	*Financed by*
A. M. Ure	Brussels (Belgium) EEC Bureau Reference Samples	—	May	EEC
A. M. Ure	Antwerp (Belgium) Assoc. Francophone de Spectr. de Masse des Solides	1	May	Antwerp Univ.
A. M. Ure	Helsinki (Finland) EUROANALYSIS IV Conference	1	August	DAFS
D. Vaughan	Amsterdam (The Netherlands) University	1	June	Vrije Univ.
T. S. West	Louvain (Belgium) IUPAC General Assembly and Council	—	August	IUPAC and Royal Society
T. S. West	Helsinki (Finland) Federation European Chem. Socs. Working Party on Analytical Chemistry	—	August	IUPAC
T. S. West	Belgrade (Yugoslavia) Int. Meeting of World Chem. Soc. Presidents	—	September	IUPAC
T. S. West	Kyoto, Matsumoto (Japan) Anniversary Meeting, Japan Soc. Anal. Chem. University	2	October	DAFS
M. J. Wilson	Turkey NATO Project on Soil	—	August	NATO
M. J. Wilson	Bologna/Pavia (Italy) 7th Intern. Clay Conference	—	September	DAFS

APPENDIX III

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

	Place	*Event*	*Date*
Department of Mineral Soils			
D. C. Bain	London	Mineralog. Soc. Clay Min. Group	November, 1980
	Aberdeen	Inst. of Physics	November, 1980
J. M. Bracewell	Reading	RSC Special Techniques and Thermal Analysis Groups	February
R. C. Mackenzie	Salford	RSC North West Region	October, 1980
	Glasgow	RSC Scottish Region	November, 1980
	London	ICTA Nomenclature Committee	January
W. J. McHardy	Cambridge	Mineralog. Soc. Clay Min. Group	April
E. Paterson	Aberdeen	2nd European Symposium on Thermal Analysis (2)	September
M. J. Wilson	London	Mineralog. Soc. Clay Min. Group	November, 1980
	London	Geological Soc. of London	March
	Cambridge	Mineralog. Soc. Clay Min. Group	April
Department of Peat and Forest Soils			
R. V. Birnie	Cambridge/ Norwich	MAFF Photo Library and Keswick College	May
H. G. Miller	Strathyre	Edinburgh Soils Discussion Group	June
	Leatherhead	CERL Biological Advisory Panel	July
G. C. Stove	Plymouth	Ann. Conf. Remote Sensing Soc.	December
	London	ARC/MAFF Meeting on Remote Sensing	January
	Glasgow	University Dept. of Geography (2)	March/April
	Coleraine	BKS Air Surveys Ltd. (2)	April/August
B. L. Williams	Aberdeen	British Society for Soil Science	September
Department of Spectrochemistry			
M. L. Berrow	Brighton	DOE Symposium on Metals in Soils and Plant Uptake	December, 1980
	Aberdeen	Euro. Soc. Nucl. Methods in Agriculture (2)	September
J. C. Burridge	Aberdeen	Euro. Soc. Nucl. Methods in Agriculture (2)	September
V. C. Farmer	Cambridge	University Seminar	February
	Runcorn	ICI Seminar	March
B. A. Goodman	London	ARC Agri. Seminar	December, 1980
	Lancaster	Int. ESR Conference (2)	March
	Aberdeen	Euro. Soc. Nucl. Methods in Agriculture	September
D. B. McPhail	Aberdeen	Euro. Soc. Nucl. Methods in Agriculture	September
B. L. Sharp	Aberdeen	Rowett Research Institute Meeting on ICP	November, 1980
A. M. Ure	Aberdeen	Trace Element Group	November, 1980
	Edinburgh	RSC Meeting on Noble Elements	March
	Sheffield	Ann. Rept. Meeting on Atomic Spec.	April
	York	British Association	September

	Place	Event	Date
Department of Soil Organic Chemistry			
G. Anderson	London	Royal Soc. Meeting on Environmental Geochemistry and Health	November, 1980
H. A. Anderson	Aberdeen	Euro. Soc. Nucl. Methods in Agriculture	September
M. V. Cheshire	Aberdeen	British Society Soil Science	September
	Aberdeen	Euro. Soc. Nucl. Methods in Agriculture	September
I. R. MacDonald	Oxford	SEB/Linnean Society	December, 1980
Department of Plant Physiology			
P. C. DeKock	London	SCI Symposium on Ca and Mg	February
	York	Stockbridge EHS Symposium	April
	Aberdeen	Euro. Soc. Nucl. Methods in Agriculture	September
A. E. S. Macklon	Aberdeen	Euro. Soc. Nucl. Methods in Agriculture	September
B. Thornton	Aberdeen	Euro. Soc. Nucl. Methods in Agriculture	September
Department of Microbiology			
M. S. Davidson	Aberdeen	Brit. Soc. Soil Science	September
D. Jones	London	Geol. Soc. of London	March
	Aberdeen	Brit. Soc. Soil Science	September
G. Lethbridge	Edinburgh	Soc. for Gen. Microbiology	September
	Aberdeen	Brit. Soc. Soil Science	September
G. P. Sparling	London	SCI Symposium	November
	Aberdeen	Brit. Soc. Soil Science (2)	September
R. E. Wheatley	Aberdeen	Brit. Soc. Soil Science	September
Department of Soil Fertility			
T. E. Edmonds	Cardiff	RSC Int. Symp. Electroanal. Chemistry (2)	April
J. W. S. Reith	London	DOE Symposium on Metals in Soils and Plant Uptake	December, 1980
Department of Statistics			
R. H. E. Inkson	Aberdeen	Postgraduate Lecture Series	
D. A. P. Mackay	Newbury	IRAD ARS Computer Users' Group	November, 1980
Department of Soil Survey			
J. S. Bibby	Edinburgh	Edinburgh Soils Discussion Group	November, 1980
D. J. Henderson and G. Hudson	Edinburgh	RSE Symposium on Inner Hebrides	September
J. C. C. Romans	Nottingham	Council of Brit. Archaeology	December, 1980
W. S. Shirreffs	Glasgow	Earth Sciences Soc. of University	May
Director			
T. S. West	London	Roy. Soc. Symp. on Trace Eelements	December, 1980
	Belfast	RSC Northern Ireland Section	June
	Aberdeen	Euro. Soc. Nucl. Methods in Agriculture	September

LIST OF PUBLICATIONS, 1980-81

The numbers appearing on the left-hand side are the MISR serial numbers for available reprints. Please quote these numbers when asking for copies of reprints from the Librarian, Macaulay Institute for Soil Research, Aberdeen, AB9 2QJ. Items marked † are maps which may be purchased at the stated price from the Department of Soil Survey at the above address. Unmarked items are unavailable in reprin: form.

1129 ANDERSON, G. Assessing organic phosphorus in soils. In: *The Role of Phosphorus in Agriculture.* ASA/CSSA/SSSA, 1980, 411-431.
A review of the factors influencing the conversion of phosphate to organic forms in soil, the nature of the phosphate esters which accumulate, and the conditions under which the esters contribute to the phosphorus nutrition of crops.

ANDERSON, H. A. Spodic horizon humus. *Migrations Organo-Minérales dans les Sols Tempérés, Nancy,* 1979. Colloq. Inter. No. 303, C.N.R.S., 1981, 269-273.
Estimation of acid-soluble spodic horizon humus forms an important part of a supplementary analysis scheme used in a study of podzolised soils. Accumulations of such typical podzolic humus are accompanied by acid-soluble aluminium and layers rich in acid-soluble phosphate, iron being notable for its comparative absence in these extracts. Acid-soluble humus bears a close resemblance to *poly*-maleic acid, which has served as a useful model compound, in both synthetic and soil incubation experiments.

1163 BACHE, B. W. and CROOKE, W. M. Interactions between aluminium. phosphorus and pH in the response of barley to soil acidity. *Plant and Soil.* 1981, **61**, 365-376.
The growth of barley is severely reduced in acid soils. In a pot experiment on two soils covering soil pH (in $CaCl_2$ solution) from 4.1 to 5.6 the critical pH for good growth varied both with the soluble aluminium level in the soil and with the phosphate treatment. At high phosphate levels, Golden Promise barley grew well at soil pH 4.3 with aluminium solubility 0.056mM, but at moderate soil phosphate levels a higher soil pH of 4.9 with low aluminium solubility of 0.010mM was necessary.

1151 BACON, J. R. and URE, A. M. Spark source mass spectrometry for the analysis of non-conducting materials. *Anal. Proc.* 1981, **18**, 356-359.
The analytical procedure and applications of spark source mass spectrometry (SSMS) are discussed and preconcentration methods for use with SSMS are considered.

1125 BAIN, D. C. and RUSSELL, J. D. Swelling minerals in a basalt and its weathering products from Morvern, Scotland. Part 1. Interstratified montmorillonite-vermiculite-illite. *Clay Minerals.* 1980, **15**, 445-452.
As part of a study of weathering products and their influence on soil clays, the main clay mineral formed by the weathering of basalt at Killundine, Argyllshire, has been characterised by X-ray diffraction, chemical, infrared and differential thermal techniques. It is an interstratification of montmorillonite, vermiculite and illite in the approximate ratio 2:1:1, all three components being dioctahedral. The swelling phases are aluminium-rich but contain little iron. The infrared absorption pattern is generally illitic in character, probably because of the dioctahedral nature of the vermiculite.

1146 BAIN, D. C. and RUSSELL, J. D. Swelling minerals in a basalt and its weathering products from Morvern, Scotland. Part II. Swelling chlorite. *Clay Minerals.* 1981, **16**, 203-212.
A swelling mineral from unweathered basalt has been shown by the use of X-ray diffraction, infrared absorption spectroscopy, differential thermal analysis and chemical analysis to have a structure intermediate between those of swelling chlorite and saponite.

BERROW, M. L. and BURRIDGE, J. C. Persistence of metals in available form in sewage sludge treated soils under field conditions. In: *Proc. Int. Conf. Heavy Metals in the Environment, Amsterdam.* Edinburgh, C.E.P. Consultants Ltd., 1981, 202-205.

Some results from two long-term field experiments with sewage sludge are reported. Considerable uptakes of Zn and Ni in particular were found and also of Cu, but not Cr, by grasses and clovers some ten years after sludge application. Changes in the extractable levels in soils at both sites suggest that the forms of Zn and Ni in sewage-sludge-treated soils alter but high levels persist. Good linear relationships between the Zn and Ni contents of grasses and the amounts extractable from the soils were found at both sites. At the one site where equivalent total amounts were applied either as a single application or annually as four successive smaller equal amounts, there was little difference in plant uptake of Zn or Cu.

†BIBBY, J. S., HUDSON, G. and HENDERSON, D. J. Soil survey map of Ardnamurchan and Morvern (combined sheet 51/52). Scale 1:50 000. Southampton, Ordnance Survey, 1980. £1.20. Folded: £1.50.

†BIBBY, J. S., HUDSON, G. and HENDERSON, D. J. Land use capability map of Ardnamurchan and Morvern (combined sheet 51/52). Scale: 1:50 000. Southampton, Ordnance Survey, 1981. £1.20. Folded: £1.50.

BLACK, J. G. (Memorial University, St John's, Canada). Computer programs for the reduction and storage of tacheometric survey data. Aberdeen, Macaulay Institute for Soil Research, Internal Report, 1981.

1121 BRACEWELL, J. M., ROBERTSON, G. W. and WELCH, D. I. Polycarboxylic acids as the origin of some pyrolysis products characteristic of soil organic matter. *J. Anal. Appl. Pyrol.* 1980, **2**, 239-248.

Previous work suggests that polycarboxylic acids can be regarded as model compounds for soil fulvic acids. The characteristic pyrolysis products of different molecular size fractions of these polymers were examined, and were found to show similarities with those obtained from soils, from water-extracted soil organic matter and from fulvic acids. One of the main products, cyclopentenone, is a highly characteristic soil pyrolysis product and has been used in the assessment of humus type. The results support the concept that the structure of natural soil organic polymers contains significant amounts of highly carboxylated chains.

1113 CHAMSAZ, M., SHARP, B. L. and WEST, T. S. Comparison of sample introduction techniques with a continuously heated graphite-furnace atomizer for atomic absorption spectrophotometry. *Talanta.* 1980, **27**, 867-872.

Continuous nebulization and analyte deposition by nebulization are compared as sample introduction methods for a continuously operated graphite furnace atomizer. The sample deposition technique is shown to combine the high sensitivity of furnace spectrometry with the precision and convenience of operation of flame methods. Continuous sample introduction resulted in extensive matrix interferences, apparently caused by variation in the atomization efficiency.

1155 CHESHIRE, M. V., BERROW, M. L., GOODMAN, B. A. and MUNDIE, C. M. The nature and origin of organic-matter-metal complexes of soil. *Migrations Organo-Minérales dans les Sols Tempérés, Nancy,* 1979. Colloq. Inter. No. 303, C.N.R.S., 1981, 241-246.

A proportion of the metals in soil is complexed with organic matter. This paper studies how plant residues are distributed amongst organic matter fractions and examines the nature of some metal complexes in both soil organic matter and plants by electron paramagnetic spectroscopy.

DeKOCK, P. C. Calcium deficient physiological disorders. *Growers Notes.* Aberdeen, North of Scotland College of Agriculture, Horticultural Division, 1981, No. 7.

A brief resumé of the similarities in the symptoms of disorders in crops attributed to calcium deficiency is made and the circumstances under which these could arise. The induced calcium deficiency could arise from the ammonium-form of nitrogen which in turn may be the result of soil waterlogging. Another factor is the predominance of growth promot-

ing hormones which may induce high potassium-calcium ratios in the tissues.

1141 DeKOCK, P. C. Iron nutrition under conditions of stress. *J. Plant Nutrition.* 1981, **3**, 513-521.
The factors which affect the uptake of iron by plants are discussed. The main fertiliser factor is phosphate, but the form of nitrogen, whether in the ammonium form or as nitrate determines the balances which pertain within the plant. Soil factors such as water deficit or excess can be quantitatively assessed.

†DRY, F. T. Land use capability map of Orkney-Mainland. Scale 1:50 000. Southampton, Ordnance Survey, 1981. £1.20. Folded: £1.50.

†DRY, F. T. Land use capability map of Orkney/Hoy. Scale 1:50 000. Southampton, Ordnance Survey, 1981. £1.20. Folded: £1.50.

†DRY, F. T. Land use capability map of Orkney-Northern Isles. Scale 1:50 000. Southampton, Ordnance Survey, 1981. £1.20. Folded: £1.50.

†DRY, F. T. Soil survey map of Orkney-Mainland. Scale 1:50 000. Southampton, Ordnance Survey, 1981. £1.20. Folded: £1.50.

†DRY, F. T. Soil survey map of Orkney-Northern Isles. Scale 1:50 000. Southampton, Ordnance Survey, 1981. £1.20. Folded: £1.50.

†DRY, F. T. Soil survey map of Orkney/Hoy. Scale 1:50 000. Southampton, Ordnance Survey, 1981. £1.20. Folded: £1.50.

1150 EDMONDS, T. E., PU GUOGANG and WEST, T. S. The determination of the ionisation constants of polymaleic acid and the stability constants of its complexes with copper. *Anal. Chim. Acta.* 1981. **129**, 69-77.
Polymaleic acid, PMA, a model compound for fulvic acid, is shown by differential pulse polarography, to possess three ionizable protons pK_1 5.05, pK_2 6.95 and pK_3 9.70 at 20°C and ionic strength 0.12 M. Between pH 5 and 9 the principal Cu complex is CuHA where A represents the fully dissociated species and has a conditional stability constant $\beta=7.80$. This agrees well with early reported values for the Cu(II)-fulvic acid complex and with literature values for the Cu(II)-humic acid complex, and shows quite strong bonding of copper by PMA.

1126 EDMONDS, T. E., PU GUOGANG and WEST, T. S. The differential pulse anodic stripping voltammetry of copper and lead and their determination in EDTA extracts of soils with the mercury film glassy carbon electrode. *Anal. Chim. Acta.* 1980, **120**, 41-53.
The differential pulse anodic stripping voltammetric behaviour of copper and lead at the mercury film-glassy carbon electrode has been studied. Simultaneous determination of these two cations in EDTA extracts of soil is described. Interferences from antimony and bismuth are discussed.

1122 FARMER, V. C., RUSSELL, J. D. and BERROW, M. L. Imogolite and proto-imogolite allophane in spodic horizons: evidence for a mobile aluminium silicate complex in podzol formation. *J. Soil Sci.* 1980, **31**, 673-684.
Examination by infrared spectroscopy and electron microscopy of the fine clays ($<0.5\mu m$) dispersed at pH 3.5 from H_2O_2-treated soil indicates that imogolite and proto-imogolite allophanes are concentrated in podzolic B_2 and B_3 horizons, and make up at least 6% of one B_2 horizon soil, which contains virtually no layer silicate clays. It is argued here that imogolite-type components are the principal source of extractable aluminium and silicon in such horizons, that they may act as cementing agent in indurated horizons, and that proto-imogolite, a soluble aluminium-silicate complex, is the predominant mobile form in which aluminium is transported to B_2 and lower horizons of podzols. Comparison of the amounts of aluminium extracted by acetic acid with those extracted by EDTA indicates that extractable aluminium in B_h and organic-rich A_2 horizons is present principally in organic complexes. It is proposed that the aluminium fulvates concentrated in these horizons are formed *in situ*.

FARMER, V. C. and FRASER, A. R. Colloidal and chemical stability of Al-Fe-Si hydroxide sols. In: *Abstracts 7th Int. Clay Conf. Italy*, 1981, 88-89.

FARMER, V. C. Possible roles of a mobile hydroxyaluminium orthosilicate complex (proto-imogolite) and other hydroxyaluminium and hydroxy-iron species in podzolization. *Migrations Organo-Minérales dans les Sols Tempérés, Nancy*, 1979. Colloq. Inter. No. 303, C.N.R.S., 1981, 275-279.
It is proposed that a hydroxyaluminium orthosilicate complex (proto-imogolite) which forms readily from orthosilicic acid and hydroxy-aluminium cationic species and which is soluble at pH <5, can transport Al from eluvial A_e horizons and deposit it in B horizons. This mechanism accounts for the fact that much of the reactive Al in B horizons is generally not in an organic complex, and exhibits the characteristics of allophane. The proposal is consistent with the apparently widespread occurrence of traces of imogolite in the B horizons of Scottish podzols and brown forest soils and with the enhanced content of orthosilicate in B horizons shown by trimethylsilylation. An example of the deposition of allophane of proto-imogolite composition from an acidic soil solution is also given. Laboratory studies of the reaction of proto-imogolite with complexing organic acids, including fulvic acid, suggest possible mechanisms for the formation of B_h and B_s horizons.

FERTILIZER RECOMMENDATIONS. Aberdeen, North of Scotland College of Agriculture College Bulletin No. 25, 1981.

1145 GAULD, J. H. The soils of Culbin Forest, Morayshire: Their evolution and morphology, with reference to their forestry potential. *Applied Geography*. 1981, **1**, 199-212.
The soils of Culbin Forest, Morayshire, are described with reference to their development through the various stages of evolution of the area, since late Glacial time. A map is given showing the distribution of 20 soil-landform units and their main characteristics are described. With the exception of humus podzols on an old dune system and immature podzols on the recently afforested dunes, the soils tend to lack profile development. The potential of the soil is assessed, according to its suitability for forestry. While afforestation has been responsible for the stabilisation of the sand dunes, only mediocre growth rates are recorded due to a deficiency in nitrogen and general nutrients. Where buried horizons are present, significant increases in yield may be anticipated.

†GLENTWORTH, R., MUIR, J. W., ROMANS, J. C. C., BIRSE, E. L., SMITH, J. and SHIPLEY, B. M. Soil survey map of Banchory and Stonehaven (combined sheet 66/67). Scale 1:63 360. Revised reprint. Southampton, Ordnance Survey, 1981. £1.20. Folded: £1.50.

GOODMAN, B. A. Some physical methods for the study of the chemical composition of soils and plants. In: *Soils and Agriculture*. Edited by P. B. Tinker. Oxford, Blackwell, 1981, 115-147.
The uses of some physical methods for obtaining chemical and structural information in the study of soils and plants have been reviewed and some potential future applications assessed.

1139 GOODMAN, B. A., McPHAIL, D. B. and POWELL, H. J. K. Electron spin resonance study of copper(II)-amino acid complexes: evidence for *cis* and *trans* isomers and the structures of copper(II)-histidinate complexes in aqueous solution. *J. Chem. Soc. Dalton Trans.* 1981, 822-827.
Mono- and bis (α-aminocarboxylate) copper(II) complexes, which have been shown previously to be involved in the uptake of copper by plant roots, have been studied in detail by electron paramagnetic resonance spectroscopy. Two isomers, each with 2 oxygen and 2 nitrogen atoms coordinated to the copper, have been shown to exist in equilibrium in solutions of the bis-complexes. With histidine, the [Cu(histidine)(histidinate)]$^+$ complex has 3 nitrogen atoms bound to the copper, whereas the [Cu(histidinate)$_2$] complex exists as an equilibrium mixture of structures having 3 and 4 nitrogen atoms bound to the copper.

1154 GOODMAN, B. A. and LEWIS, D. G. Mössbauer spectra of aluminous goethites (α-FeOOH). *J. Soil Sci.* 1981, **32**, 351-363.

Synthetic goethite specimens have been prepared by a variety of experimental methods, and it has been possible to incorporate large quantities of Al($\leqslant$30 mole %) into the structure. A range of particle sizes, which were dependent upon both the extent of aluminium substitution and the experimental conditions were obtained. Mössbauer spectra have been recorded for a large number of samples and show that high levels of Al-substitution combined with small particle sizes have a dramatic effect on the magnetic properties of the mineral. The application of Mössbauer spectroscopy to the identification of secondary iron oxide phases in soils is thus complicated by aluminium substitution and some of the difficulties are discussed.

GOODMAN, B. A. Mössbauer spectroscopy. In: *Advanced Techniques for Clay Mineral Analysis.* Edited by J. J. Fripiat. Amsterdam, Elsevier, 1981, 113-137.

A state-of-the-art assessment of the use of Mössbauer spectroscopy in the study of clay minerals is presented.

GOODMAN, B. A. Mössbauer spectroscopy. In: *Advanced Chemical Methods in Soils and Clay Minerals Research.* Edited by J. W. Stucki and W. L. Banwart. Dordrecht, D. Reidel, 1980, 1-92.

The basic theory, equipment and experimental procedures for performing ^{57}Fe Mössbauer measurements are presented and some examples of the applications of the technique to the study of clay minerals, mineral alteration reactions and soils are discussed in detail. Particular attention is given in these discussions to the strengths and weaknesses of the technique for each type of application. Some possible future developments of the applications of Mössbauer spectroscopy in clay minerals research are indicated.

GOODMAN, B. A. Use of Mössbauer and EPR spectroscopy in soil plant studies. In: *Agricultural Science Seminar on Soil Root Relationships.* London, A.R.C., 1981, 37-40.

The applications of Mössbauer and EPR spectroscopy to the study of the chemical and structural forms of metals in soils and plants are described. Both techniques are able to provide extensive chemical information not readily available from other sources, although Mössbauer spectroscopy can only be used with iron-containing materials and EPR spectroscopy is limited to the study of species with unpaired electrons, i.e. free radicals and paramagnetic metal ions.

1135 GUZEL, N. (Cukurova Univ., Adana, Turkey) and WILSON, M. J. Clay-mineral studies of a soil chronosequence in Southern Turkey. *Geoderma.* 1981, **25**, 113-129.

The principal clay mineral in a series of Vertisol terrace soils associated with the Ceyhan River in Southern Turkey is an iron-rich smectite which was deposited as part of the alluvial sediment. Comparison of the soil clays from different terraces reveals changes affecting the smectite which are consistent with interlamellar adsorption of material that may be organic in nature.

1148 HART, J. W. (University of Aberdeen) and MacDONALD, I. R. Phototropism and geotropism in hypocotyls of cress (Lepidium sativum L). *Plant, Cell and Environment.* 1981, **4**, 197-201.

Light and gravity are the two major environmental forces regulating the orientation of the emerging seedling. This study investigates the interaction of these forces in the seedling and their relative importance in determining directional growth.

1140 HART, J. W. (University of Aberdeen) and MacDONALD, I. R. Phototropic responses of hypocotyls of etiolated and green seedlings. *Plant Sci. Letters.* 1981, **21**, 151-158.

Phototropism is one of two major guidance systems by which a seedling can orientate itself with respect to its environment. This comparison of the phototropic responsiveness of green and etiolated dicotyledonous seedlings shows that etiolated seedlings possess only a poorly developed

photosensitivity. The phototropic response occurs in the hypocotyl, but is dependent on the export of substances formed in the cotyledons in response to light.

1115 HENDERSON, R. (A.R.C. Unit of Statistics, Edinburgh) and RAGG, J. M. A reappraisal of soil mapping in an area of Southern Scotland. Part II. The usefulness of some morphological properties and of a discriminant analysis in distinguishing between the dominant taxa of four mapping units. *J. Soil Sci.* 1980, **31**, 573-580.
Results of a two stage random sample survey were used to give information about the usefulness of some morphological properties for distinguishing between the four taxonomic units, all gleys or gleyed soils, described in part 1 of this paper. A multivariate logistic method of discriminant analysis was used on the data. The classifications by soil surveyors and by the statistical analysis were mainly in good agreement, but many generally accepted B horizon criteria used for assessing hydromorphism were of little value in discriminating between the soils under study. Depth to gleying and secondary lithology were valuable distinguishing properties while matrix colour value, texture and structure of the B horizon were useful in some instances. Serious consideration of the role of statistical techniques, such as discriminant analysis, is advocated both as a guide to those who design taxonomies and as an aid to field identification.

1128 JONES, D. Scanning electron microscopy of cryo-fixed sporodochia of *volutella ciliata*. *Trans. Brit. Mycol. Soc.* 1980, **75**, 311-314.
Biologists are often in a dilemma when examining specimens in the electron microscope since they have to decide whether or not the prepared material faithfully retains its natural three-dimensional configuration. This paper compares three methods of preparing a soil fungus, *volutella* sp., in the scanning electron microscope. The conclusion is that cryo-fixation, whereby the specimen is quickly frozen and water is retained, is most likely to give a true-life image of certain morphological features under investigation. Dehydration generally results in distortion of the specimen.

1124 JONES, D., WILSON, M. J. and TAIT, J.M. Weathering of a basalt by *pertusaria corallina*. *Lichenologist*. 1980, **12**, 277-289.
The weathering phenomena following the encrustation of basalt by the lichen *pertusaria corallina* have been studied by scanning electron microscopy and other techniques. Lichen weathering resulted in the decomposition of felspars and ferromagnesian minerals as well as in the degradation of secondary clay minerals. The active agent appears to have been oxalic acid excreted by the fungal part of the lichen. Lichens can be regarded as convenient models for the assessment of microbiological effects on the decomposition of rock minerals and the consequent release of plant nutrients into the soil.

1164 KHALIGHIE, J., URE, A. M. and WEST, T. S. Atom-trapping atomic absorption spectrometry of arsenic, cadmium, lead, selenium and zinc in air-acetylene and air-propane flames. *Anal. Chim. Acta*. 1981, **131**, 27-36.
Atom trapping atomic absorption spectrometry has been applied to the determination of Cd, Pb, Se and Zn in an air-acetylene flame and As in an air-propane flame to yield sensitivities that are respectively 18, 48, 3, 80 and 60-fold better than those of the conventional technique. Reducing the zone of observation above the atom-trap to measure in the region of highest atom density further increases the sensitivity for Cd, Cu, Pb, Se and Zn by factors of 2.5, 4.5, 2.5, 5.5 and 1.5-fold respectively. The sensitivity for Cd may be increased 2-fold by precoating the silica collector tube with 1000 ppm V or 3-fold with 1000 ppm Cu.

1131 MacDONALD, I. R. and HART, J. W. An inhibitory effect of light on the germination of mustard seed. *Ann. Bot.* 1981, **47**, 275-277.
The sensitivity of seed germination to light varies from one species to another, some species being inhibited, others being stimulated while many are unaffected. Although it has previously been thought that mustard was among those species unaffected by light it is here shown that light is inhibitory under conditions of low water potential.

MacEWAN, D. M. C. (Hythe, Kent) and WILSON, M. J. Interlayer and intercalation complexes of clay minerals. In: *Crystal Structures of Clay Minerals and their X-ray Identification.* Edited by G. Brown and G. W. Brindley. 3rd ed. London, Mineralogical Society, 1980, 197-248.

The various types of interlayer and intercalation complexes which can be formed with smectite, vermiculite and kaolinite minerals are reviewed with particular emphasis on the use of such complexes for clay mineral investigations using X-ray powder diffraction.

McKAY, D. A. P. and STOVE, G. C. Digital processing and analysis of Landsat MSS data (Fucino CCTS) on a Honeywell 66/80 computer. *Computer Applications.* 1980, **7**, 936-965.

Landsat satellite data collected from the multispectral scanner are now widely recognised as a unique digital terrain database for thematic mapping at medium and small scales. A description is given of a suite of computer programs developed using a Honeywell 66/80 computer, to provide information on extracted subsets of a scene, compare the reflectance intensities on all bands once properly registered, and produce output in the form of simple statistics and shaded line printer maps.

1166 MACKENZIE, R. C. The constituents of soil clays: Their importance and origin. *Eighth Conf. Clay Mineralogy and Petrology, Teplice, Czechoslovakia.* Edited by J. Konta. Prague, Univ. Karlova, 1981, 9-17.

The properties of many soils depend on the behaviour of the clay fraction, which may contain crystalline clay minerals, crystalline and highly disordered accessory minerals, organic matter and soluble salts. These need not always appear as distinct phases, but several can occur in one particle: consequently, investigation of their properties is difficult. Present knowledge indicates that highly disordered accessory minerals can have an effect on soil-clay properties disproportionate to the amount present, but how far this is modified by compound formation or complexing with organic matter cannot yet be assessed. The relative contribution of different constituents is likely to vary from soil to soil.

MACKENZIE, R. C. Thermoanalytical methods in clay studies. In: *Advanced Techniques in Clay Mineral Analysis.* Edited by J. J. Fripiat. Amsterdam, Elsevier, 1981, 5-29.

International agreement on the nomenclature and definition of thermoanalytical methods has enabled these to be grouped and classified, and their potential, or likely potential, in clay research can now be suitably assessed. Only a few of the available techniques are currently widely used, but a study of developments over the past few years suggests that the measurement of acoustic, optical, electrical and magnetic characteristics deserve much more attention in relation to the light they can shed on fundamental and practical clay problems.

1153 MACKLON, A. E. S. and SIM, A. Cortical cell fluxes and transport to the stele in excised root segments of *Allium cepa* L. IV. Calcium, as affected by its external concentration. *Planta.* 1981, **152**, 381-387.

In an earlier paper, it was proposed that uptake of calcium by onion root segments, from an external concentration of 1mM, was by passive diffusion, and that calcium was maintained at less than equilibrium concentration in each root cell by an outwardly directed metabolic pump. These proposals have now been tested over a range of external calcium concentrations including those normally found in soil solution, bearing in mind the likelihood that the concentration of free calcium in the cytoplasm was much lower than formerly assumed. Over the whole range of Ca concentrations tested, the original proposal was found to be valid for the outer cell membrane, but Ca concentration in the vacuole is now considered to be determined by an inwardly directed pump from the cytoplasm.

1136 MILLER, H. G. and MILLER, J. D. Collection and retention of atmospheric pollutants by vegetation. *Proc. Int. Conf. Ecol. Impact Acid Precip., Norway,* 1980. Edited by D. Drablos and A. Tollan. Norway, SNSF, 33-40.

In addition to material reaching an ecosystem in rain, there is a further input of material trapped from the atmosphere on the surface of vegetation. The collection and retention of such air-borne salts and gases by vegetation are discussed with illustration drawn from the literature and from current investigations at the Macaulay Institute. Results from the latter are used to show that, for most elements, much of the additional material scavenged from the atmosphere by forests is derived from the sea, and arrives in solution form as mist or fine raindrops. For sulphur, recent measurements indicate that this input adds 8 and 12 kg S per ha per yr to the rainwater collected beneath trees at two sites, but it is considered that the greater part of this is derived from SO_2 or acidic aerosols.

MILLER, H. G. Nutrient cycles in forest plantations, their change with age and the consequence for fertilizer practice. In: *Productivity in Perpetuity, Proceedings of CSIRO, Canberra,* 1981. Canberra, 187-199.
From studies of nutrient cycles it is shown that, because of efficient cycling and collection and retention of atmospheric nutrients, closed-canopy forests make relatively low demands on the pool of available soil nutrients. By contrast, newly planted forests have high nutrient demands until the foliage biomass and nutrient cycles are fully developed. It is suggested, therefore, that the increased use of fertilizers in forests during the twentieth century mainly reflects the great expansion of afforestation, and that after canopy closure the classical nineteenth century concepts of self maintaining cycles remain essentially correct

†MILLER, H. G., MILLER, J. D. and COOPER, J. M. Tables of biomass and accumulated nutrients at different growth rates in thinned plantations of Corsican pine. Aberdeen, Macaulay Institute for Soil Research, 1980. 50p each from the Librarian.
Tables are presented giving biomass of foliage, live branches, dead branches, stem wood, stem bark, stump and lateral roots before thinning, and the weight of stem plus branches, stem plus crown and stem plus both crown and stump removed in thinnings, in five year age intervals to age 80 for six growth rates (Yield Classes 6, 8, 10, 12, 14 and 16) of *Pinus nigra* var. *maritima* (Ait.) Melv. In addition the accumulated weights of nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, manganese and copper are presented for the same categories, ages and growth rates.

1143 PATERSON, E. Intercalation of synthetic buserite by dodecylammonium chloride. *Amer. Mineral.* 1981, **66**, 424-427.
An intercalation technique developed using a synthetic model compound, buserite, may prove to be of value in the characterisation of manganese oxide minerals in soils. Treatment of buserite with a quaternary ammonium salt expands the basal spacing from 10Å to 25.6Å thus reducing the likelihood of confusion with clay minerals such as illite on X-ray diffraction examination.

PATERSON, E. The value of differential scanning calorimetry in assessing the physical and chemical properties of particle surfaces. *Proc. Second Eur. Symp. Thermal Anal.* Edited by D. Dollimore. London, Heyden, 1981, xxiii-xxix.
The use of differential scanning calorimetry (DSC) in the study of surface phenomena is discussed with reference to two minerals common in soils, goethite and imogolite. The influence of physical and chemical factors on the loss of adsorbed water from the surface of these minerals can be assessed from the DSC curves.

PATERSON, E. and SWAFFIELD, R. Influence of various cations on the thermal decomposition of humic acid. *Proc. Second Eur. Symp. Thermal Anal.* Edited by D. Dollimore. London, Heyden, 1981, 281-285.
The application of lime is an important stage in the amelioration of podzolic soils for agricultural use. In this investigation the effect of calcium, magnesium and barium ions on the thermal decomposition of humic acid, separated from a podzol, has been studied using differential scanning calorimetry and thermogravimetry. The changes in thermal behaviour can be related to the uptake of these ions and the influence of

other factors, such as pH, on the exchange reaction can be readily assessed from the DSC curves.

†THE PEAT AND TERRAIN CATEGORIES OF LEWIS AND NORTH HARRIS. Map and accompanying geometrically corrected and enhanced Landsat image at 1:100 000 scale. Aberdeen, Macaulay Institute for Soil Research, and Farnborough, Royal Aircraft Establishment, 1981. £3 plus p.p. from the Department of Peat and Forest Soils.

PRINGLE, A. W. (Univ. Lancaster) and BAIN, D. C. Saharan dust falls on North-West England. *Geographical Mag.* 1981, **53**, 729-732.
The mineralogical composition of a dust fall on North-West England on 28-29 November, 1979, and the meteorological conditions leading to its deposition have been investigated. The fibrous mineral palygorskite, which is typical of soils in arid environments, is present in the fine fraction and a back-tracking trajectory has traced the path of the dust across the Atlantic, suggesting a probable origin in western Africa at about 15°N.

PYATT, D. G., CRAVEN, M. M. and WILLIAMS, B. L. Peatland classification for forestry in Great Britain. *Proc. Inter. Symp. Classification of Peat and Peatlands, Hyytiälä, Finland, Sept.* 1979. 351-366.
Peat samples taken from 194 sites throughout Britain were analyzed both physically and chemically to check the effectiveness of the present peatland classification scheme, based mainly on vegetation, and used in predicting the potential of peatland types for afforestation. Analytical results show that the 5 groups, comprising 18 types, are distinguished mainly by the concentrations of N, P and K in the peat and to a lesser extent by soil moisture content.

1114 RAGG, J. M. and HENDERSON, R. (A.R.C. Unit of Statistics, Edinburgh). A reappraisal of soil mapping in an area of Southern Scotland. Part I. The reliability of four soil mapping units and the morphological variability of their dominant taxa. *J. Soil Sci.* 1980, **31**, 559-572.
A two-stage random sample survey was made to study the composition of four common mapping units already mapped in the Central Lowlands of Scotland. The four mapping units, named from Aberdona, Caprington, Macmerry and Rowanhill series, were sampled at densities proportional to their mapped area. In terms of their A horizon textures, the mapping units had percentage reliabilities of 84, 96, 93 and 97 respectively. Drainage class reliability scores were 70, 80, 72 and 70 respectively. On the basis of taxonomic units within the mapping units, percentage reliabilities ranged from 43-60 but no one minor constituent soil exceeded 16% in any of the units studied. Although complex according to currently accepted guidelines, the authors conclude that such mapping units should be named according to the dominant taxonomic unit. The authors also conclude that errors of identification due to inadequate definitions of taxonomic units have contributed to some of the low levels of reliability of taxonomic units within mapping units and recommend that soil taxa should be defined more precisely in Scotland. In order to test the variability of the taxonomic units, upon which the above mapping units are based, means and variances are calculated for selected properties and are examined. The main conclusion reached from these calculations is that the four taxonomic units (and hence also mapping units) under study are not equally variable in the area of investigation.

REITH, J. W. S. Trends in the nutrient status of Scottish soils. *Proc. Third Study Conf. Scottish Agricultural Colleges, Peebles,* 1980. Scottish Agricultural Colleges, 1981, 3-7.
The paper assesses whether the amounts of lime, phosphorus and potassium applied in Scotland are likely to maintain the current soil levels and crop productivity. Results for advisory soil samples are used to indicate trends in soil nutrient status. Estimates are given of the annual quantity of lime required to maintain reasonably adequate levels, of the amounts of phosphorus and potassium needed for optimum production, and of nutrients lost by leaching, removed in crops and animal products and returned in farmyard manure and slurry. The need for increasing the recommended rates of phosphorus and potassium for fields consistently producing high yields is noted.

1142 REITH, J. W. S. and BURRIDGE, J. C. Lime and nutrient requirements for producing herbage on peat. In: *The Effective Use of Forage and Animal Resources in the Hills and Uplands.* Editor: J. Frame. British Grassland Soc. Occasional Symp. No. 12, 153-154.
Based on earlier work, the paper gives the amounts of lime, N, P and K required to establish a good sward on acid peat. Field experiments were carried out on a newly established sward to determine, at three rates of fertilizer N, the P and K requirements of herbage cut three times annually for five years, and to measure the effects of a range of trace elements on yield and composition. The results show the amounts of P and K required with 0, 60 and 120 kg N per ha per cut. Applying trace elements had very little effect on yield but increased their contents in the herbage.

ROBERTSON, J. S. Trees in the Fife landscape: land use in Fife. In: *St Andrews Conf. Report.* Edited by R. J. Mitchell, St Andrews University, Department of Adult Education and Extra-Mural Studies, 1980

1134 SCOTT, N. M. Evaluation of sulphate status of soils by plant and soil tests. *J. Sci. Fd. Agric.* 1981, **32**, 193-199.
The sulphate status of ten acid soils from north Scotland was evaluated using seven extracting agents and a measurement of isotopically exchangeable sulphur. The soil values were correlated with the yield, yield response, and the sulphur uptake of oats grown in Mitscherlich pots. The best crop relationships were given by heat soluble sulphur and sulphate extracted by potassium dihydrogen phosphate and sodium bicarbonate solutions, but the phosphate method is preferred since it dissolves both readily soluble and adsorbed sulphate, and much less organic matter.

1130 SCOTT, N. M., BICK, W. and ANDERSON, H. A. The measurement of sulphur-containing amino acids in some Scottish soils. *J. Sci. Fd. Agric.* 1981, **32**, 21-24.
Cysteic acid and methionine sulphone were measured in soil hydrolysates by ion exchange chromatography. In four cultivated top soils, these amino acids accounted for 19-31% of the carbon-bonded sulphur fraction, measured as the difference between total organic sulphur and total organic sulphate, but only 8% in a peat. When the carbon-bonded sulphur fraction is measured directly by reduction with Raney-Nickel the amounts obtained are lower and are accounted for by the amino acids to the extent of 80-100% in the mineral soils and 50% in the peat. It would seem, therefore, that the Raney-Nickel reduces only the amino acid fraction of the carbon-bonded sulphur.

SHARP, B. L. Laser remote sensing of atmospheric pollutants. *Proc. Anal. Div. Chem. Soc.* 1979, **16**, 197-199.
A brief review of laser methods for atmospheric pollution monitoring is given. The advantages and disadvantages of the various techniques are outlined and the salient features of their practical implementation discussed.

†SHIPLEY, B. M. Land use capability map of Stirling (Sheet 39). Scale 1:63 360. Revised reprint. Southampton, Ordnance Survey, 1980. £1.20. Folded £1.50.

†SHIPLEY, B. M., STEVENS, J. H., LAWRENCE, E. and JARVIS, R. A. Soil Survey map of Stirling (Sheet 39). Scale 1:63 360. Revised reprint. Southampton, Ordnance Survey, 1981. £1.20. Folded £1.50.

1144 SINCLAIR, A. H. Availability of magnesium to ryegrass from soils during intensive cropping in the glasshouse. *J. Agric. Sci., Camb.* 1981, **96**, 635-642.
Ten Scottish soils were cropped with ryegrass in the glasshouse, without addition of Mg, until growth virtually ceased. Magnesium uptake and the corresponding changes in soil Mg properties were measured. The equilibrium Mg-concentration ratio Mg/(Ca,Mg), determined from the Mg Q/I isotherms was a good indicator of both Mg uptake and the Mg concentration in the ryegrass over the entire cropping period. A value of 0.16 was needed in the early stages of cropping to give 0.20% Mg in the dry matter, the content in spring grass above which incidence of hypomagnesaemia in grazing animals may be reduced. Non-exchangeable

Mg reserves were released from seven soils, amounting to between a fifth and a third of the total Mg uptake. These 'reserves' were released too slowly to maintain Mg levels of 0.20% in the ryegrass.

SMITH, B. F. L. The use of organosilicon derivatives in a study on the weathering of soil parent materials. M.Sc. Thesis, University of Aberdeen, 1981.

1137 SPARLING, G. P. Microcalorimetry and other methods to assess biomass and activity in soil. *Soil Biol. Biochem.* 1981, **13**, 93-98.
The activity and weight of organisms in soil are useful indices of the level of fertility and can be used as indicators of toxicity or pollution. Seven methods of assessing the soil population, including a microcalorimetric technique, were investigated to determine which of them are applicable to Scottish soils. There was good agreement between the measurements of biomass, ATP content, respiration, heat production and enzyme (amylase) activity. The heat production (microcalorimetry) from soils is a useful additional technique for assessing the activity of the organisms.

SPARLING, G. P. and VAUGHAN, D. Soil phenolic acids and microbes in relation to plant growth. *J. Sci. Fd. Agric.* 1981, **32**, 625-626.
Phenolic acids are widespread in soils and can markedly affect plant growth. In laboratory experiments the acids were rapidly decomposed by soil microorganisms. Decomposition was more rapid in soil from a potato crop than from peas, barley or fallow soil. Caffeic, p-coumaric, ferulic or p-hydroxybenzoic were toxic to wheat at 10^{-3}M concentrations, ferulic being by far the most toxic. The toxicity was almost completely removed by growing the plants in the presence of soil organisms that decomposed the phenolic acids.

1138 SPARLING, G. P., ORD, B. G. and VAUGHAN, D. Microbial biomass and activity in soils amended with glucose. *Soil Biol. Biochem.* 1981, **13**, 99-104.
Most organisms in soil (the soil biomass) are starved of food and spend much of their life in dormant and resting phases. Plant roots exude substances which stimulate the biomass into growth and greater activity. This increased activity around roots may affect plant growth and nutrient content. Glucose was added to soil to mimic exudation from the root. Following this glucose amendment the biomass, adenosine triphosphate content, and enzyme synthesis (amylase and dehydrogenase) increased and these increases were related to the amount of substrate added.

1127 STOVE, G. C. and BAGOT, K. E. (Space Dept., Royal Aircraft Establishment, Farnborough). Current resource mapping and environmental monitoring applications using Landsat MSS data in Scotland. *Proc. Sixth Canadian Symp. Remote Sensing, Halifax, Nova Scotia,* 1980, 551-557.
Using the photogrammetric digital mapping facilities at the Macaulay Institute and advanced Image Analyser at RAE Farnborough, four examples are given of the application of LANDSAT MSS data for resource mapping and environmental monitoring in Scotland. Contrast enhancement and multispectral classification techniques are described. More specialised techniques, including Principal Components Analysis, have also been used to enhance and classify surface marine features and to distinguish snow from cloud in upland areas.

1133 STOVE, G. C. and HULME, P. D. Peat resource mapping in Lewis using remote sensing techniques and automated cartography. *Int. J. Remote Sensing.* 1980, **1**, 319-344.
The application of methodology developed for peat resource survey has illustrated the usefulness of multi-level and multi-band aerial photography in classifying LANDSAT multispectral imagery. Ground truthing to characterise the thematic maps plotted from the aerial photography and LANDSAT imagery was based primarily on vegetation surveys. The results of this work are illustrated with a series of maps and photographs and the usefulness of the approach is assessed.

STOVE, G. C., BIRNIE, R. V., CAIRNS, J. G. and RITCHIE, P. F. S. Land use survey of Buchan based on satellite remote sensing. Aberdeen, Remote Sensing Unit, Department of Peat and Forest Soils, Macaulay Institute for Soil Research, 1981. Report commissioned by Grampian Region Physical Planning Department.

This report presents the results of a study commissioned by the Grampian Region Department of Physical Planning on the production of a land use map of the Buchan Area from LANDSAT satellite imagery. Computer-assisted experiments conducted by the survey team at the Macaulay Institute and at the U.K. National Remote Sensing Centre, RAE Farnborough on the identification of particular land use types has shown that it is possible to differentiate at least 10 classes, including grain, root and grass crops, on the satellite images. Field checks have shown a remarkable fidelity between satellite image information and actual ground cover. On this basis, a land use map of Buchan (1979) has been prepared and the procedure for annual revision of this preliminary map is outlined

1149 VAUGHAN, D. and ORD, B. G. Uptake and incorporation of ^{14}C-labelled soil organic matter by roots of *Pisum Sativum* L. *J. Exper. Bot.* 1981, **32**, 679-687.

^{14}C-labelled soil organic matter fractions are taken up by pea roots but fulvic acid is taken up to a greater extent than humic acid after 18 hours of culture. The uptakes are due to the soil organic matter being sorbed on to the root surfaces as well as to an active uptake process. Only the low molecular weight materials are taken up actively irrespective of the soil fraction from which they are derived. It is suggested that fulvic acid alone is taken up by plant roots from the soil solution.

1152 WEST, T. S. Soil as the source of trace elements. *Phil. Trans. R. Soc. Lond.* 1981, B**294**, 19-39.

The factors which were responsible for the varying contents of the bio-essential elements B, Co, Cu, Fe, Mn, Mo and Zn and those which have less well defined beneficial effects, Cr, Ni, Se, Si and V, in igneous and sedimentary rocks were reviewed. Physical and biological weathering followed by the incorporation of organic matter yield soils which hold part of their store of trace elements in plant-available forms. These and the influence of various management factors, e.g. drainage, acidity, organic matter content, fertilizer application, are discussed in relation to trace element availability for plants, animals and man.

WEST, T. S. Preliminary evaluation of the data acquired during the Aberdeen Thermal Survey, by computer processing. Report to Seminar on Europe's first city-wide airborne thermal survey, April, 1981.

1132 WILSON, M. J. and DUTHIE, D. M. L. Some aspects of intrastratal alteration of biotite in the Old Red Sandstone. *Scot. J. Geol.* 1981, **17**, 65-72.

Following investigations of the mineralogy of Old Red Sandstone soils and rocks, the biotite in some of these rocks has been characterized by various methods. It was found that the mineral has not been extensively altered and has lost little potassium, magnesium or iron. These observations are inconsistent with a hypothesis suggesting that the decomposition of biotite in rocks like the Old Red Sandstone provides a major source of pigmentary iron oxide.

1147 WILSON, M. J., JONES, D. and McHARDY, W. J. The weathering of serpentinite by *Lecanora arta*. *Lichenologist*. 1981, **13**, 167-176.

The weathering phenomena brought about by the growth of the lichen *Lecanora atra* on a magnesium silicate rock (serpentinite) have been studied mainly by X-ray diffraction and scanning electron microscopy. Oxalic acid generated by the lichen, has the effect of preferentially extracting magnesium leaving behind an X-ray amorphous silica gel, which is often of a fibrous nature. The magnesium so extracted generally precipitates as insoluble, extracellular, magnesium oxalate dihydrate. This salt is of interest since it should, in theory, be capable of incorporating large amounts of heavy metal ions into its structure, as indeed has happened, thereby isolating and removing them from the growing lichen.

1123 WILSON, M. J. and McHARDY, W. J. Experimental etching of a microcline perthite and implications regarding natural weathering. *J. Microscopy*. 1980, **120**, 291-302.
Matching cleavage surfaces of a potassium felspar were hydrothermally etched in an autoclave for increasing periods of time. Arrays of etch pits were quickly developed and were exactly duplicated on matching cleavage surfaces, thus indicating that they represent true crystal dislocations. These dislocations are associated mainly with intergrown lamellae of another felspar phase and possibly with a particular direction of twinning. The information gained in this study could be useful for the interpretation of the naturally etched felspars which are widespread in Scottish soils.

1156 WILSON, M. J., RUSSELL, J. D., TAIT, J.M., CLARK, D. R., FRASER, A. R. and STEPHEN, I. Swelling hematite/layer silicate complex in weathered granite. *Clay Minerals*. 1981, **16**, 261-277.
The red mottled patches of a deeply weathered granite in Aberdeenshire contain a layered siliceous hematite with swelling properties. Its X-ray diffraction pattern shows a basal specing of 36Å which expands to 40Å on glycerol solvation and contracts to 33.5Å on heating. Selected-area electron diffraction reveals a composite hematite-layer silicate pattern, with a definite orientation relationship beween the two components. Infrared spectroscopy suggests that the silicate component resembles ferruginous pyrophyllite, and that the hematite component has many of the characteristics of a soil hematite of platy morphology. Electron-probe analysis of individual particles indicates an (Fe+Al): Si ratio of 6:1, which can be accounted for in terms of a structure made up of a double hematite unit consisting of twelve octahedral sheets terminated on both sides by a silicate sheet.

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.~~ Bush Estate
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, Surrey, 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.
Rothamsted Experimental Station	Harpenden, Herts., AL5 2JQ.
Welsh Plant Breeding Station	Plas Gogerddan, Aberystwyth, Dyfed, SY23 3EB.
Wye College, Department of Hop Research	Ashford, Kent, TN25 5AH.