ROTHAMSTED RESEARCH

Report for 1976 - Part 1

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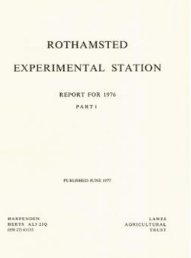

General Report

L. Fowden

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GENERAL REPORT

L. FOWDEN

The year 1976 was most exceptional. The growing season from September 1975 to August 1976 was the driest since records began in 1728. Mean air temperature during the summer months of June, July and August was also the highest on record. The hot, dry conditions produced the largest soil water deficit (411 mm) at Rothamsted since calculations were started in 1964. Nationally, many crops suffered severely from drought, and yields were erratic. Cereal grain filled poorly in many regions and spring-sown barley at harvest frequently resembled pine needles in cross-section. The unusually early cereal harvest curtailed our expected field programme. In summary, 1976 proved to be a year most farmers and many field experimenters will wish to forget.

Lawes Trust Committee. Two members retired from the Committee at the end of the year after long periods of service. Professor Sir Vincent Wigglesworth had served on the Committee since 1954, and Professor W. T. J. Morgan since 1964. We thank them both for their valuable contribution to the work of our Governing Body, and for the interest and wisdom they brought to discussions of the Station's scientific affairs and research programme. We welcome Professor T. W. Goodwin, CBE, FRS (University of Liverpool), and Professor J. L. Harley, FRS (University of Oxford), as new members of the Committee from January 1977.

Staff. C. G. Butler retired in April, after spending almost the whole of his scientific career at Rothamsted. He joined the staff in 1939, becoming Head of the Bee Department in 1944, and in 1972 Head of the Entomology Department after its amalgamation with the Bee Department to form the Station's largest scientific group. He made outstanding contributions to knowledge of honeybee management and behaviour, and was recognised internationally for his work on bee pheromones. He served as President of the Royal Entomological Society (1971–73) and was awarded the OBE and elected a Fellow of the Royal Society in 1970.

Several other members of staff retired during the year after long periods of service. D. A. Boyd (Statistics Department) joined the Station in 1937 and became an authority on the design and evaluation of field experiments, especially those relating to fertiliser practice; in this work he was most closely associated with scientists of the Agricultural Development and Advisory Service (ADAS) of the Ministry of Agriculture, Fisheries and Food (MAFF). Blanche Benzian (Chemistry Department) and M. J. Allen (Field Experiments Section) had each served Rothamsted for 35 years. For many years Benzian worked in collaboration with the Forestry Commission, and made important contributions to knowledge of the nutrition of conifer seedlings during establishment. Allen was identified particularly with the Station's visitor programme: each year he enthusiastically explained our experiments to hundreds of visitors, being especially understanding of the needs of school parties. S. A. W. French (Botany Department) joined Rothamsted in 1929: he played an important role in the Department's field experimental programme and growth analysis work. H. H. Le Riche (Pedology Department) retired after 30 years' association with research in soil mineralogy and W. A. H. Burton, foreman of Rothamsted Farm, after serving the Station for 21 years.

During the year, E. Lester assumed the Headship of the Plant Pathology Department, T. Lewis became Head of the Entomology Department, and T. Woodhead, Head of the Physics Department. Their previous affiliations were given in last year's Report.

Two appointments to Headships of Departments were made with effective dates in 1977: Professor P. B. Tinker, Head of the Department of Plant Sciences in the University

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of Leeds, to the Headship of the amalgamated Chemistry and Pedology Departments, renamed the Soils and Plant Nutrition Department, from March, and Dr. R. K. Scott, Reader in Agronomy at the University of Nottingham's School of Agriculture, Sutton Bonington, to the Headship of Broom's Barn Experimental Station from April.

The deaths of P. J. D. Fletcher and F. H. Palmer, members of staff of the Engineering and Maintenance Services Department, are reported with regret.

Honours and awards. W. A. H. Burton was awarded the British Empire Medal in the New Year's Honours, 1977.

Mary R. Truter received the Chemical Society's Award for Structural Chemistry for 1975 in recognition of her advancement of knowledge of the molecular conformations of co-ordination complexes of the alkali and alkaline earth metals. T. Lewis was awarded the 1976 Huxley Memorial Medal and Prize given by Imperial College London 'for ability to carry out research in some branch of natural science in which Professor Huxley was distinguished'. M. Elliott was nominated as the Holroyd Memorial Lecturer of the Society of Chemical Industry in recognition of his outstanding contributions to research on pyrethroid insecticides.

The Station was honoured to receive the Queen's Award for Technological Achievement 1976. The Grant of Appointment was presented to the Station by Her Majesty's Lord Lieutenant of the County of Hertfordshire, Maj.-Gen. Sir George Burns, at a ceremony held in July. Representatives of national and local government and of other organisations connected with Rothamsted's work attended. The Award marked the successful development by the Station of highly active, safe insecticides from the pyrethroid group. Two such compounds, resmethrin and bioresmethrin, licensed by the National Research Development Corporation for commercial production are already widely and successfully used against pests in the home, in aircraft, and in food stores.

Buildings. The building for the Departments of Entomology and Molecular Structures was almost completed at the end of the year, and staff hope to move into their new laboratories in spring. Detailed plans for a new Stores building, for which funds are approved, and working drawings of the other buildings forming part of the long-term development, have been submitted for planning permission to the local authority.

Demonstrations of research

Rothamsted. Subject Days featuring the Station's work on 'Cereal Pests and Diseases' were held in June, when more than 500 people attended the three-day event. Our visitors represented a wide cross-section of the agricultural community, and included more farmers than on previous Subject Days. The number of overseas visitors, mainly scientific and agricultural counsellors of London embassies, also increased. We were particularly pleased to see Lord De Ramsey, Treasurer, and other members of our governing body, The Lawes Agricultural Trust Committee, the Hon. J. J. Astor, Chairman, Sir William Henderson, Secretary, and many of the senior officers of the Agricultural Research Council (ARC), and Dr. K. Dexter, Director General of ADAS and his senior colleagues. Laboratory exhibits were grouped to illustrate work on wheat bulb fly, cereal aphids and virus, cereal nematodes, miscellaneous pests of cereals, foot and root diseases, leaf and ear diseases and grain microflora, and the effects of minimum tillage practices on pests and diseases. Field demonstrations complemented many of the indoor exhibits. In a year when record numbers of aphids were present on the nation's cereal crops, the exhibit relating infestation to virus diseases was timely. Visitors touring the field experiments on 24 June saw Broadbalk being sprayed with an aphicide, the first occasion such a spray has been applied to this field that has grown wheat for 133 years.

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Broom's Barn. An Open Day was held in late June to demonstrate the Station's laboratory-based research and field trials on sugar beet and other arable crops. Almost 300 people attended including a large number of beet growers. A few days earlier, the Station was host to more than a hundred members of the Royal Agricultural Society of England. The Earl of Stradbroke, Lord Lieutenant of the County of Suffolk, attended, as did two past chairmen of the Sugar Beet Research and Education Committee, Col. Sir Edmund Bacon (Lord Lieutenant of the County of Norfolk) and Sir Peter Greenwell, and the present Chairman, Mr. J. N. Holmes. The theme for the day's highly successful discussions and demonstrations was 'Drilling-to-a-stand: maximise your yield'.

Other exhibitions. On the occasion of N. W. Pirie receiving the Rank Prize for Nutrition, a demonstration of work on plant protein extraction was mounted. This emphasised the use of the product as a dietary supplement in areas of the world where children suffer from serious protein deficiencies.

In March, some of the work done at Rothamsted was included in the National Spring Potato Demonstration at Stoneleigh. The topics shown included: the control of potato scab by irrigation and the possibilities for control by foliar applications of chemicals; and the identification and control of potato cyst-nematodes and the importance of the correct mixing of nematicides into the soil.

Visits and visitors. On 30 June the Station welcomed the Secretary of State of the Department of Education and Science, the Rt. Hon. Fred Mulley, and Mrs. Mulley. The Department finances almost half of the work carried out in institutes funded by the ARC, and so the occasion provided an opportunity to demonstrate to our distinguished visitors examples of the Station's research achievements.

During the year, delegations of senior scientists from several countries visited Rothamsted. A group of five Polish agriculturalists, headed by Dr. H. Burczyk, Deputy Minister of Agriculture, spent four days in Harpenden in May discussing problems of cereal and legume grain production. Later in the year we received a delegation of Russian agriculturalists, led by Mr. A. I. Oliashev, under the terms of the agreement on Anglo-Soviet Co-operation in Agricultural Research; the group had particular interests in research on grassland management. After a lapse of some years, we were delighted to entertain visitors from China again. The party of five molecular biologists, led by Mr. Shen Shan-chung of the Plant Physiology Institute in Shanghai, were visiting research centres in Britain under the auspices of The Royal Society–Academia Sinica exchange agreement. Professors G. Filipovski and M. Herak, members of a Yugoslavian delegation hosted by The Royal Society spent a day at Rothamsted discussing aspects of our research on soils.

Many overseas scientists came on individual visits to the Station under arrangements made by the British Council. These visits generally lasted one or two days, but the Council also sponsored longer attachments providing training in research methods for agricultural scientists from a variety of countries. Rothamsted was included in visits arranged by the Central Office of Information for Dr. Kim (Director General of the Office of Rural Development) and Dr. Choi (Director of the Crop Improvement Research Centre) from South Korea, and for Encik Yahya bin Talib (Deputy-Director, Economic Planning Unit) and Encik Abu Hassan bin Haji Omar (Deputy Secretary-General of the Ministry of Land and Regional Development) of Malaysia. Senior French and Brazilian agriculturalists came to discuss ways of achieving collaboration in research on themes of mutual interest to their countries and our scientists.

K. A. Lord (Chemical Liaison Unit) is spending six months in Brazil at the Instituto Biologico at São Paulo, where he is advising on the development of a pesticide residues

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programme. C. A. Edwards (Entomology Department) spent a shorter period at the University of Agricultural Sciences, Bangalore, organising teaching and seminar programmes on soil pests. F. G. W. Jones (Nematology Department) visited Cyprus for four weeks to advise the Food and Agriculture Organisation of the United Nations on the control of the golden cyst-nematode. Barbara Mosse (Soil Microbiology Department) spent two months visiting research centres in Australia, where her knowledge of the role of mycorrhiza in enhancing phosphate uptake by plant roots was especially welcome in view of the low phosphorus status of many Australian soils. Late in the year, L. Fowden also visited Australia to review the research programmes of the CSIRO Divisions of Plant Industry (Canberra) and Irrigation Research (Griffith). Earlier he visited Bulgaria as a member of a party of British scientists taking part in a colloquium on 'The Planning and Application of Scientific Research to meet National Need' sponsored by the Great Britain-East Europe Centre and the Bulgarian Committee for Science, Technical Progress and Higher Education. The visit provided interesting opportunities to see the Nikola Pushkarov Institute of Soil Science in Sofia and an agro-industrial complex of 60 000 ha near the old capital of Veliko Tirnovo.

Weather and crop growth. The winter of 1975/76 was relatively mild and dry, and provided generally good conditions for farm work. Autumn-sown cereals were drilled into good seed beds, and all spring-sown crops were planted early. This was especially so for the sugar-beet crop at Broom's Barn, which was sown earlier than ever before. The summer growing season was remarkable for the very high temperatures and unprecedented drought. The mean daily maximum temperatures for June, July and August were 4·8, 4·5 and 3·4°C higher than the long-term average, whilst rainfall in every month from January to August was substantially less than the long-term mean, and only 40% of the average for the eight-month period. The drought broke in September and a very wet spell between early September and mid-December provided three-fifths of Rothamsted's total 1976 rainfall. Harvesting of potatoes and sugar beet became increasingly difficult during this period.

The unusual weather produced very variable and, occasionally, remarkable crop growth and yields. An experiment on winter barley grown in Great Knott I gave a plot yield of 9·07 t ha^{-1}, much the best ever recorded at Rothamsted for this cereal, whether spring- or autumn-sown. In sharp contrast, one plot of spring-sown barley on the Exhaustion Land gave a recorded yield of 0·01 t ha^{-1}, largely due to the loss of severely shrivelled grain over the back of the combine harvester.

In the wheat variety experiment at Rothamsted on a site free from soil-borne diseases, the two semi-dwarfs, Maris Fundin and Hobbit, gave the best yields of 6·45 and 6·42 t ha^{-1}, respectively.

In a year when grass grew extremely poorly, and new grass leys failed to establish, forage maize, sown in May and given 25 mm irrigation at Rothamsted and none at Woburn, gave similar mean yields at 9 t ha^{-1} dry matter at harvest on 22 September (Woburn) and on 5 October (Rothamsted).

Drought also severely affected the national potato crop and some yields of unirrigated crops were very poor, often less than 10 t ha^{-1}. Other yields were surprisingly good, and the best plot on Broadbalk (unirrigated) gave 37·5 t ha^{-1} of total produce. Some very large plot yields (up to 81 t ha^{-1} total produce) were obtained in a components of yield trial on light sandy soil at Woburn when irrigation, nematicide and enhanced farm practices were applied (see Nematology Department report p. 212). Another problem this year, particularly in the variety King Edward, was second growth in the form of chain tuberisation giving a crop composed of a mixture of earlier- and later-formed small potatoes, which may cause trouble during storage.

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By early June, the sugar-beet crop looked unusually good and well-advanced. However, the combination of high temperatures, desiccating winds and extreme soil moisture deficits encountered in late June and July caused severe wilting and defoliation and restricted subsequent root growth. In more normal summers, the experiments have shown that with this deep-rooted crop irrigation gives little increase in sugar yields, but the recent sequence of drier winters and hotter summers is causing many growers to reassess the potential for, and the economics of, irrigation systems.

Multi-disciplinary field experimentation. At present, there is considerable national interest in the related topics of methods of attaining maximum potential yields of agricultural crops and of the factors governing or imposing limitations on yield. The causes of between-season and between-site differences in yield are still inadequately understood, as are the reasons for national average yields for many crops being less than half the maximum potential. The different factors are likely to show many interactions and comprehensible results are unlikely to be obtained without a multi-disciplinary approach combining many scientific skills.

This year we started the first of a series of multi-disciplinary experiments to determine the causes of seasonal variation of yield of field beans (*Vicia faba* L.) on Rothamsted's Clay-with-flints soil. Eventually we hope to determine the treatments necessary to attain maximum yields in contrasted years.

Eight departments — Entomology, Field Experiments, Insecticides and Fungicides (Chemical Liaison Unit), Nematology, Physics, Plant Pathology, Soil Microbiology and Statistics — are co-operating in the experiment, and the first year's results are reported by the Field Experiments Section (p. 150). In this year's exceptional weather conditions, yields of normally-treated beans in this experiment and elsewhere on the farm were little more than 1 t ha^{-1}, but the best yields in the experiment, where many of the limiting factors were removed, ranged up to 4 t ha^{-1}.

Soil fertility, crop nutrition and quality. Our interest in the ability of different soils to sustain crop productivity has continued and during the last three years we have succeeded in increasing yields of winter wheat (Cappelle–Desprez) grown continuously on the difficult soil at Saxmundham Experimental Station to equal the yields on similarly manured plots on Broadbalk at Rothamsted. This is probably due to the increased use of fertilisers and to more timely cultivations. Meanwhile, new work begun in the Biochemistry Department seeks fuller information about factors influencing the quality of cereals, especially the storage proteins of the barley grain.

Soil nitrogen and crop growth. Experiments in 1976 confirmed previous indications that carbon disulphide inhibits nitrification of aqueous ammonia or urea fertilisers injected under grass in November, thereby reducing losses of N by leaching of nitrate and decreasing the nitrate content of herbage. A solution of trithiocarbonates, which is more easily handled and less obnoxious than carbon disulphide, behaves similarly for it generates carbon disulphide when in contact with soil. Either formulation almost completely inhibits nitrification in Rothamsted soils for two months and leads to a more uniform supply of nitrogen to grassland throughout the growing period. Nitrapyrin ('N-Serve') behaves differently, being relatively ineffective as an inhibitor for several months after late autumn injection, but then inhibiting nitrification well into the following spring. Used together, the two inhibitors seem to offer a possibility of regulating nitrification during a six-month period.

It is important to have information about the movement of plant nutrients through soil profiles after rainfall or evaporation, and now the Chemistry Department have

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developed a model able to predict the behaviour of nitrate and chloride ions. Good agreement is observed between the measured and predicted distribution of these ions, but the model must be further developed to allow for biological as well as physical processes occurring in the soil profile.

Availability of soil nutrients. In Part 2 of this Report, we document the remarkable long-term value of residual nutrients for barley grown continuously on the Hoosfield Exhaustion Land. Given only nitrogen fertiliser, plots from which farmyard manure and P and K fertilisers have been withheld since 1901 have given grain yields between 4·22 and 4·75 t ha^{-1}. These yields equal or exceed the national average for barley, and our evidence suggests that, at the present rate of removal of phosphorus by the crop, the residues built up by fertiliser applied last century may last for a further 70 years.

Mycorrhizal fungi living symbiotically in plant roots can enhance phosphorus uptake by plants. Work in the Soil Microbiology Department has indicated that phosphorus uptake by a range of crops, including maize, barley, lucerne, clover and onions, is greatly increased by the fungal hyphae extending from the mycorrhizal roots into the surrounding soil. Crop husbandry practices, especially fertiliser and pesticide use, are likely to affect the distribution of the mycorrhizal fungi in the soil, and in some soils the fungi may be too sparse or inefficient to influence nutrient uptake at critical periods of plant growth. The possibility of inoculating field soils with mycorrhizal fungi of high efficiency is being assessed, aided by the extensive collection of fungal endophytes maintained at the Station. At present the inability to culture the fungi in the absence of living plant material imposes practical limitations, but inoculation techniques, especially with tropical soils of low phosphorus status, have considerable future potential.

Manipulation of protein content of cereals. A re-examination of the results of many experiments conducted with cereals at Rothamsted in the past 20 years has indicated that the seed protein content of wheat is influenced by nutritional and seasonal factors; extreme limits of the nitrogen content of grain of spring wheat range from 1·6–3·1% and of winter wheat from 1·2–3·0% (Chemistry Department report, pp. 85–86). Although environmental and crop husbandry practices can produce large differences, we still know too little about the nature of the protein complex of cereal seeds and the associated biosynthetic processes to explain these effects adequately.

A major programme recently begun in the Biochemistry Department seeks much fuller information about the proteins of barley grain. Previous methods for extracting the major storage proteins, prolamin (hordein) and glutelin, from barley endosperm have been rigorously re-examined and much improved procedures developed, permitting an almost quantitative extraction of the prolamin complex that constitutes between 40–50% of the endosperm protein. The individual polypeptides forming this complex have been characterised by a variety of techniques, and systems developed for cell-free synthesis of certain of the polypeptides using isolated polysomes. These techniques have been used to compare the storage proteins present in normal and 'high-lysine' barleys. This work forms part of an EEC Common Research Programme on Plant Protein Improvement of which Rothamsted is a contracting member. In the longer term, we hope to use information gained about the genetics and control of synthesis of cereal storage protein in the improvement of strategies for breeding varieties with improved protein content and quality.

Crop pests and diseases. The mild winter, long hot summer and unusually wet autumn were reflected in atypical pest situations. Aphid migrations began early and many species were very numerous, particularly those infesting cereals. Populations declined sharply

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as crops ripened, and predators, especially ladybirds, increased. Large populations of cutworms developed at the end of the summer causing serious damage to vegetable crops, and following the onset of autumn rains, slugs reappeared in large numbers in surface soils causing further damage to root crops and attacking autumn-sown cereals. An article in Part 2 of this report reviews slugs as agricultural pests, and attempts an economic assessment of the damage they cause to Britain's major arable crops.

Aphid resistance to insecticides. There is now no doubt that organophosphate-resistant *Myzus persicae* are widespread throughout sugar-beet growing areas of Britain, and that similar resistance is present in aphid populations infesting potatoes in the seed growing regions of Western Scotland and Northern England. A kit developed in the Insecticides and Fungicides Department enables field workers to detect the presence of resistance readily; the proportion of resistant individuals in a population can then be determined by electrophoretic methods. Other work has indicated that this proportion changes little during the growing season: therefore early monitoring of resistance in the over-wintering population can provide an early indication of its likely incidence throughout the season. Resistance to organophosphorus insecticides in aphid populations at Rothamsted was undoubtedly a contributory factor in the spread of potato virus Y within our King Edward seed crop, leading to its rejection for the second year in succession.

The increasing unreliability of organophosphorus compounds will result in greater immediate dependence on carbamates and conceivably in future on the newer pyrethroids being developed for agricultural use. We have begun longer-term studies to devise strategies for limiting the development of resistance to these classes of insecticide.

Synthetic pyrethroids. The potential future role of the highly active photostable pyrethroids recently discovered at Rothamsted have been established more clearly by further extensive field evaluation against major crop pests by various organisations in several countries. Their broad spectrum of activity makes them attractive for many pest problems; one major use already identified is against pests of cotton, particularly in Africa and the USA. Within the past year, we have concentrated on evaluating new advances in terms of structure-activity relationships in the expectation that this knowledge will prove useful in the discovery of further active compounds exhibiting additional favourable properties.

Potato seed stock health. The technique of apical meristem culture brought great benefit to the potato crop by providing a means of eradicating virus. However, the complementary benefits, in terms of greatly improved control of fungal and bacterial infection, anticipated from the use of stem cuttings, have not materialised. Fungicides applied to seed effectively control some tuber diseases in the resultant crop, but not gangrene, a major disease of stored tubers. Fungicides applied to the crop immediately after harvest provide good disease control, if tubers are not subsequently damaged. We are trying to obtain better disease control by improving the efficiency of fungicides and by seeking the means whereby stem cutting material becomes re-infected with pathogens, so that this can be prevented and the health of seed stocks raised to an extent that the ware crop can benefit.

Major new equipment and associated research. The mobile rain shelter is now fully operational. The shelter was used first for an experiment on tillage in 1975. This year it provided the site for a more ambitious experiment in which our physicists and botanists jointly investigated the physiological responses of spring barley, at different stages of

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crop growth, to water stresses of various severities. During the year the accommodation for field recording instruments at the Little Knott site has been expanded, and drains constructed to provide flood-protection for the experimental plots covered by the rain shelter.

The new rain tower and wind tunnel complex adjacent to the Plant Pathology Department is nearing completion and instruments are being installed with the guidance of our physicists. The complex will facilitate the detailed study of the physics and biology of particle and droplet distribution and deposition in crops and on plant surfaces. Initially, a major aim will be to develop a better understanding of the epidemiology of cereal diseases, emphasising those that are splash-borne, in order to improve control measures. Eventually, we expect its value to extend beyond plant pathology and into other disciplines concerned with the behaviour of particles, droplets and also volatiles in the crop environment.

The Molecular Structures Department were provided with a new Enraf-Nonius CAD-4 automatic X-ray diffractometer. This instrument is proving very facile in operation, and now molecular structures and conformations can be determined more rapidly and accurately than previously. The Department offers a structural determination service to scientists at other institutes within the Agricultural Research Service (ARS). Funds have been authorised for the purchase of new coupled mass spectrometry-gas chomatography equipment for the Insecticides and Fungicides Department. We have chosen the VG-Organic 70-70F instrument, which will enhance the capability of our chemists engaged in the synthesis of new insecticides and in the characterisation of substances affecting pest behaviour.

The installation of the ICL System 4-72 computer has been delayed because problems have persisted in meeting the standard of air conditioning required within the computer room and the stringent noise standards within the vicinity of the computer building. This will have repercussions for the starting date of the dual System 4 service because the joint ICL/Rothamsted Project Team has been delayed in developing the software. Notwithstanding these difficulties, computing has continued to grow, both in volume and variety. The early role of the computer as a calculating tool operating on numerical values is gradually becoming secondary to a newer use in information processing, where operations are on strings of characters. Users in many agricultural research institutes linked to the Rothamsted computer seek advice on the planning and development of their computer work, and since computing is now a matter of prime interest within the ARS, Rothamsted's Computer Department has had to make choices on behalf of the Service as a whole, without sufficient guidance on future computing policy within the ARS. A newly-appointed Liaison Officers Consultative Group, whose members are drawn from institutes served by the Rothamsted computer, should help to identify the future directions in which computing will develop.

Soil surveying: winter rain acceptance map. However anomalous it may seem in a year characterised by outstanding drought, there is a need for better estimates of flood flows and levels in streams so that culverts, bridges and flood banks can be designed adequately and river channels graded accordingly. It is particularly important to be able to predict areas of flooding following extreme storms. Unfortunately, although long-term records of rainfall are reasonably comprehensive for Britain, records of flood flows are too scanty to form the basis for reliable predictions. For reservoir spillway design, a technique for estimating floods from the more reliable rainfall statistics is especially desirable. A large number of catchments now have records of river flow over various lengths, and these indicate the amount of the storm rainfalls flowing from the catchment in a short period. It is then necessary to predict corresponding percentage runoffs for ungauged

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areas as a step towards converting rainfall to river flows. The main factor influencing this percentage between catchments is likely to be the soil cover, the effect of which needs quantification.

Cost prevents large numbers of very accurate physical measurements being made over each catchment, but the Soil Survey of England and Wales, working with the Institute of Hydrology (Natural Environment Research Council) has now portrayed soil variability on a map of Winter Rain Acceptance at a scale of 1:1 million. Using soil profile information acquired in many surveys throughout the country and interpreted in hydrological terms, the map shows the distribution of five classes of land. Where possible the relevance of the classes has been confirmed by statistical examination of runoff data from gauged catchments.

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