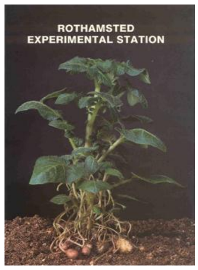
ROTHAMSTED RESEARCH

Rothamsted Experimental Station Report for 1983



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P. B. Tinker

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INTRODUCTION

This has been an eventful and productive year. As part of the divisionalization of Rothamsted the Soils Division has been set up. This comprises the Soil Microbiology Department and the Soils and Plant Nutrition Department, which now incorporates part of the previous Physics Department. This Division aims to deal with soil properties and composition, soil management, soil-root relationships and plant nutrition. The formation of the Division will in particular allow closer links between work on soil microorganisms, nitrogen fixation and mycorrhizas in the two departments. As the first example, all work on vesicular-arbuscular (VA) mycorrhizas is this year placed in the Soil Microbiology report. The important work on carbon demand by *Rhizobium* can also be more readily linked with work on nitrogen nutrition and turnover in the field, if this proves appropriate. The genetic studies in the Soil Microbiology Department are developing well, both in relation to *Rhizobium* and vesicular-arbuscular mycorrhizas. Work on the physiology of these symbioses should benefit from the genetic studies, and will in turn help to guide programmes aimed at improving the organisms genetically.

Amongst other work of note during the year, the prediction system for nitrogen requirement is now at a state when it can be more extensively tested on a series of farms, in collaboration with ADAS. Further confirmation of the relation of losses of fertilizer nitrogen in spring with rainfall on different soils offers great possibilities for adjusting late N top-dressings.

Work on plant composition is now moving into a more mechanistic phase, with studies on the way in which plants use potassium for control of water potential and turgor, and how they maintain this when potassium is not freely available. The importance of take-all disease has been re-emphasized by the multidisciplinary experiments at Rothamsted; and a project to relate the incidence of the disease to soil type is reported this year.

New approaches to the determination of the structure of typical soil clays, and their interaction with water, are reported here. With new appointments, and new equipment, this section of the Division is now well placed to make significant advances on the implications of clay structure for soil bulk behaviour.

We report this year work in two areas which are expected to grow in the near future. In one, the effect of straw on the nitrogen transformations and losses in the soil has been measured; the recent massive interest in straw burning makes this very topical. In the second, the detailed effects of root impedance due to a compacted layer in the soil have been monitored. With the large investment in subsoil cultivation at present, often based on very slight evidence, we feel this should be pursued on a wider range of soil. This should have useful connections with the collaborative work with Silsoe College, formerly the National College of Agricultural Engineering, on mole drainage reported here.

Despite the serious financial constraints, we were able to appoint a few staff to work on particular projects, including the analysis of Soil Survey samples for trace elements, and work on surface chemistry of soils. In addition, funds were provided for a new

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Philips X-ray diffraction spectrometer, as an improved replacement for obsolescent equipment. This will greatly aid our work on clay mineral structures.

SOIL MICROBIOLOGY

Sampling the soil microflora

The object of this work is to extract cells from soil by mild physico-chemical procedures which allow sampling with defined and controlled bias. Multiplication and degenerative changes in microorganisms are avoided so that the sample is as representative as possible of the microflora in the soil. Soil has been dispersed by chemical treatment and a defined portion of the microflora extracted by physical methods. The sample is free from soil debris and is contaminated only with glycocalix and mucilaginous material. The endogenous oxygen uptake of these cells has been measured polarographically as an indicator of metabolic activity. The concentration of DNA in the sample has been determined by extraction and fluorimetry, as a measure of the concentration of cells. The microflora sampling procedure is now being optimized with respect to these two values, with the object of preparing as pure and as undamaged a suspension of cells as possible. (Macdonald; Sen)

Comparative anatomical studies of wheat roots invaded by *Gaeumannomyces graminis* var. *tritici* (Ggt) and *Phialophora graminicola* (Pg)

In axenic culture Ggt produces more disease on regions of the root within 10 cm of the seed than on more distal parts. Root cortex death, indicated by the absence of stainable nuclei in the cells, has been implicated in the process of infection by Ggt and Pg. Root cortex death was affected by the form of nitrogen supplied; both the percentage of cortical cells containing stainable nuclei and the longevity of the nuclei in the upper root region were greater when plants were given nitrate rather than ammonium nitrogen or a mixture of the two forms. Root cortex death in the distal region was little affected by forms of nitrogen. (Brown; Chandler and Gibson)

Genetic approaches to VA mycorrhizal fungi

Although the VA mycorrhizal fungi have not been cultured independently from their host plants, spores can readily be isolated from soil around infected roots. The spores can be germinated and limited hyphal growth observed on sterile agar medium. It is necessary to have strains of the same species which can easily be differentiated for any studies on genetic recombination. We are attempting to isolate naturally occurring strains that produce spores that can germinate under conditions which are usually inhibitory, such as the presence of heavy metal ions or fungicides in the medium, so that the transfer of this property can be followed.

We have isolated DNA from spores and are cloning fragments as 'gene libraries' in the bacterium *Escherichia coli.* This will allow us to propagate DNA sequences from VA mycorrhizal fungi and we hope to identify specific genes.

These studies should yield valuable information about the relationships within and between the species and genera of the VA mycorrhizal fungi, and enable us to identify particular strains in field trials. (Hirsch; Burton, Spokes and Vivian)

Spread of mycorrhizal infection in developing root systems

The suggestion that differences in pH tolerance may exist within a single species of a vesicular-arbuscular mycorrhizal fungus was tested using two isolates of *Glomus caledonium,* from soil at pH 7·5 and 5·5 respectively. Inoculum from pH 5·5 was only

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slightly more tolerant to reduced pH in a pot experiment than was that from pH 7·5. Interspecific, rather than intraspecific differences seem to determine the composition of fungal populations at different levels of soil pH.

In sand culture aluminium at concentrations similar to those found in soil solution of acid soil (approx. 2 mg l^{-1}) greatly reduced the colonization of oat by *G. caledonium*. In the absence of Al, good infection occurred at pH 4·5. Manganese was ten times less inhibitory. (Stribley; Tinker and G. M. Wang)

Rapid spread is a major determinant of the efficacy of mycorrhizal fungi in enhancing P uptake by the host. We need to understand the controlling factors as background for potential practical application of mycorrhizas.

The mechanism by which P inhibits infection was investigated using our system for measuring spread in single roots (*Rothamsted Report for 1982,* Part 1, 270). Addition of P did not greatly affect the growth of adventitious roots or the rates of extension of infected segments within them. Its principal effect was to increase the mean delay in infection of individual roots and its variation, thus reducing the mean overall rate of colonization. (Stribley; Gnekow and Tinker)

Infection of roots was tested in onion seedlings grown at two light intensities and with different nitrogen treatments which alter the root carbohydrate levels. Roots contained less carbohydrate in the NH_4-N [$(NH_4)_2.SO_4$] than in the NO_3-N [$Ca(NO_3)_2.4H_2O$] treatment, and the differences were greater in shaded plants. Mycorrhizal infection *(Glomus mosseae)* was decreased by shading and by adding nitrogen, especially NH_4-N. The negative effect of shading on infection was more severe with NH_4-N than with NO_3-N. These results show a correlation (r=0·81) between root carbohydrate levels and early VA mycorrhizal infection in young seedlings, thereby suggesting that the carbohydrate theory of Björkman (*Plant and Soil* (1970) **32,** 588–610) for ectomycorrhizas also applies to VA mycorrhizas. (Hayman; S. R. Wang)

Mycorrhizal inoculum production

Root organ cultures, derived from a callus of *Trifolium repens* cv. Mari which has been transformed by *Agrobacterium rhizogenes,* have been infected *in vitro* with *Glomus caledonium* and the infection maintained during subculture. It is hoped that *Glomus caledonium* cultured by this method will be suitable for use as inoculum under field conditions. (Carr; Hinkley and M. G. Jones, Biochemistry Department)

Applications

Mycorrhizas and growth of transplanted onions. Nearly all commercially-grown celery, about 20% of onion and 10% of leek are grown from transplants raised in the glasshouse on peat media. These mycotrophic crops provide an interesting potential application for mycorrhiza since quantities of inoculum needed are small and infection can take place under controlled conditions.

In a field experiment (with Dr R. Hiron of Kirton EHS) onion seedlings raised by the Hassey tray system were infected by a mycorrhizal fungus isolated from Kirton soil. It was necessary to amend the commercial transplant compost with soil to ensure infection. At harvest, onions raised from uninfected transplants had 10% of their root length infected whereas the inoculated treatments reached 40%. There was no effect of mycorrhiza on yield, possibly because of the excessive phosphate level of 150 mg kg^{-1} soil of bicarbonate-soluble P. Future work will be done on soil of low P status and will test the effect of water supply. (Stribley; Snellgrove)

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Mycorrhiza, *Rhizobium* and white clover in Welsh hill grasslands. The contribution of mycorrhizal inoculants to clover establishment in hill pasture improvement was examined at Pwllpeiran EHF in experiments set up in 1982 in cooperation with the Welsh Plant Breeding Station, Aberystwyth. Clover was introduced directly into the flail-mowed native turf as transplanted seedlings (pre-inoculated) or as seeds in pelleted inoculum (see *Rothamsted Report for 1982,* Part 1, 215–216). In this second year clover dry matter was still increased by treatments applied in the first year; for pelleted material yields were: Control, 423; inoculated, 631; phosphate, 829; inoculated+phosphate, 1800 (all in kg ha^{-1}). In the first year native endophytes infected about half the root system without phosphate, but only about 27% with phosphate, by the end of the season. Inoculation increased infection percentage by about 20%, both with and without phosphate. (Hayman; Grace)

The success of a mixed VA mycorrhizal inoculant in experiments where *Rhizobium* inoculum were given to all treatments was reported last year (*Rothamsted Report for 1982,* Part 1, 215–216). Much more effort is now being directed towards establishing a viable practical system of dual inoculation in Welsh hill soils.

As the first step, experiments have been established at three locations, on a humic brown podzolic soil of the Parc Series, a raised relatively well drained peat overlying the same soil and on a wet poorly drained peat overlying a stagnohumic gley of the Mynydd Series. The objective is to assess how site-specific the response is and the relative importance of the two inoculants. Large multi-seeded pellets containing mycorrhiza, *Rhizobium,* white clover seeds, lime and nutrients have been developed. These were either broadcast or 'slot' seeded into flail-mown swards, to avoid the complete destruction of the grazing potential. In 1983, which was very hot and dry, clover growth was so poor that no harvest was possible. Nevertheless, visual scoring indicated some benefit from the VA mycorrhizal inoculant at two sites; full harvests will be made next year.

Plants on both control and *Rhizobium*-inoculated plots were nodulated. Some of these nodules were derived from strains not related to those used in the inoculant, showing that indigenous *Rhizobium* strains were present. Roots of plants from control plots were well infected by indigenous VA mycorrhizal fungi, which were different from the strains used in the inoculum. In the presence of superphosphate this infection was approximately halved. Plants from the inoculated plots were well infected, both with and without superphosphate, showing the value of introduced inoculum for maintaining high levels of infection in fertilized soils. (Day, Hayman; Davidson, Fyson, Gee, Grace and O'Shea)

Genetic work and studies of the carbon cost of N_2 fixation

The quantity of N_2 fixed by a legume crop depends upon the amount of carbohydrate available for fixation in the root nodule and the efficiency with which this carbon is used. Methods which measure the efficiency of carbon allocation to fixation (Witty, Minchin and Sheehy, *Journal of Experimental Botany* (1983) **145,** 951–963) have been applied to define the factors which could be manipulated genetically to improve efficiency.

Genes determining host range and N_2 fixation in *Rhizobium* are known to be linked and located on large plasmids, some of which can be transferred between strains. We have compared different *R. leguminosarum* plasmids in the same bacterial background and the same host plant cultivar (*Pisum sativum,* var. Dark Skinned Perfection) and found more than a two-fold difference in efficiency. These differences were determined principally by the carbohydrate cost per electron transferred by nitrogenase and by the number of electrons required to reduce each N_2; (a variable proportion of electrons are wasted by the enzyme in the reduction of protons to H_2).

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We have found that some legume/*Rhizobium* combinations are able to change their diffusion resistance to O_2 rapidly (Sheehy, Minchin & Witty (1983) *Annals of Botany* **52,** 565–571). This resistance is, at least in the short term, a major factor controlling the total carbon used in N_2 fixation. Differences in both O_2 diffusion resistance *per se* and its control have been found between different legume species (Witty, Minchin, Sheehy, and Ines Mingues (1984) *Annals of Botany* **53,** 13–20) and between different cultivars of the same variety *(Pisum sativum)*. (Witty; Beringer and Hirsch)

Measurement of N_2 fixation and nitrogen transfer to associated crops

The project funded by the ODA to develop methods for measuring N_2 fixation in grain legumes and the rhizospheres of cereal crops, in collaboration with International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), has been extended for a further three years and will include studies of fixation in *Phaseolus* and the transfer of fixed nitrogen to associated maize crops, in collaboration with Centro Internacional de Agricultura Tropical (CIAT).

Studies of N_2 fixation associated with sorghum and millet are continuing, and similar results to those reported last year for sorghum (*Rothamsted Report for 1982,* Part 1, 222) have been obtained for millet. Incorporation of ^{15}N into the roots and shoots of millet was evident within three days of exposure to $^{15}N_2$ and continued thereafter.

Isotope dilution experiments using individual plants from a genetically diverse population of millet which had been shown to have a poor response to N fertilizer in field experiments at ICRISAT have continued. Comparisons are being made between estimates of N_2 fixation using the isotope dilution method, $^{15}N_2$ incorporation, C_2H_2 and allene reduction. (Giller; Davitt, Day and Edwards)

Transfer of fixed nitrogen to associated crops. Glasshouse experiments were carried out to evaluate the transfer of fixed nitrogen from N_2-fixing to non-N_2-fixing companion crops.

The small water fern *Azolla filiculoides* was grown together with lowland rice under simulated paddy conditions. The soil was amended with ^{15}N-labelled ammonium sulphate. The difference in ^{15}N enrichment between rice alone and that with *Azolla* indicated that about 10% of the nitrogen in the rice crop had been derived from (unlabelled) N_2 fixed by the fern, but the total nitrogen content of the rice crop was not affected.

In a parallel experiment french beans *(Phaseolus vulgaris)* were grown together with maize *(Zea mays)*. Both fertilizer uptake and total nitrogen content of the maize was reduced to less than a quarter by the presence of beans in the same pot. Isotopic analysis indicated that 15% of the nitrogen in the resulting nitrogen deficient maize crop had been derived from the french beans. (Witty; Dr A. Balasubramanian, Tamil Nadu Agricultural University)

Inoculant production using moist peat-based cultures

As reported in the Annual Report for 1982, production of moist peat-based *Rhizobium* inoculants was started by a new company (New Plant Products Ltd) which has been set up by the British Technology Group. The company is now owned by the Agricultural Genetics Company (AGC).

During the year all aspects of manufacturing technology, i.e. carrier selection and sterilization, packaging and fermenter design were investigated and the company is now in a position to produce inoculants that meet the internationally accepted quality control standard of 1×10^9 *Rhizobium* gm^{-1} carrier at production and in excess of 1×10^8 *Rhizobium* gm^{-1} at the recommended expiry date.

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Several batches of inoculants were prepared and exported to countries in Europe and Africa and performed well. A microbiologist has been appointed by the AGC to produce inoculants and be responsible for the development of novel inoculant products. (Day; Davidson, Fyson and Gee)

Granular inoculants. The majority of *Phaseolus* seed sown in the UK is dressed with captan, making normal slurry inoculation impossible due to toxicity problems. Following earlier work on alternative formulations (*Rothamsted Report for 1981*, Part 1, 212) a less expensive pelleted *Rhizobium* inoculant with superior shelf life and drilling characteristics has been developed using sand, gum arabic and plasterer's whitening. (Day; Gee)

Staff and visiting workers

Pauline Mather retired in May after working as a personal secretary in the Department for nearly eight years; she was replaced by Janet Why who had previously worked as a specialist typist in the Soils and Plant Nutrition Department. Margot Ewens transferred in January to the Soils and Plant Nutrition Department. P. Edwards joined the Department in March to work with K. Giller on a project funded by ODA and Rachel Burton joined in October to work with Penny Hirsch on a one year project funded by BTG. A. Vivian from Thames Polytechnic started a six-month sabbatical leave in September working on the genetics of *Rhizobium* and VA mycorrhizal fungi with Penny Hirsch.

This year two projects funded by NRDC came to an end and all five staff have had to find alternative appointments. Anne Warner left in March, P. Gee became a permanent member of staff in April, Mary Hinkley and G. Carr left in September and A. Fyson in December.

Sandwich Course Students in the Department included R. Wadey, working on *Rhizobium,* Jean Warburton working on VA mycorrhizal fungi and Yasmin Khan working on *Rhizobium* and VA mycorrhizal fungi.

Our research programme benefited from work done by the following overseas scientists that have spent time in the Department: A. Balasubramanian (India), R. Bhatnagar (India), S. Chaudry (Pakistan), L. Skot (Denmark) and C. Wang (China), Irene Koomen (The Netherlands) and Manuela Giovannetti (Italy).

In November H. F. Bitanyi returned to Tanzania after spending three years in the Department and obtained his Ph.D.

J. Day, A. Fyson, K. Giller, Penny Hirsch and J. Witty participated in the Fifth International Symposium on Nitrogen Fixation in Noordwijkerhout (The Netherlands); J. Day and K. Giller participated in a coordination meeting at the IAEA in Vienna (Austria); K. Giller spent six months working at ICRISAT and lectured at universities in India; J. Day spent three weeks in Bangladesh and Rome advising on inoculant production; D. Hayman gave a course on mycorrhiza at the Tamil Nadu Agricultural University, India; R. Macdonald participated in the Second International Congress on Endocytobiology in Tubingen (W. Germany): J. Beringer participated in the following Conferences: the Third International Symposium on Microbial Ecology in Lansing (USA), the Fifth International Symposium on Nitrogen Fixation in Noordwijkerhout (The Netherlands), Biosciences '83 at the Pasteur Institute, Paris (France) and a meeting on Modern Biology Applied to Agriculture in the Vatican (Italy). He also joined the Visiting Groups at the Boyce Thompson Institute, Cornell (USA) and the Max Planck Institute for Plant Sciences at Cologne (W. Germany).

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SOILS AND PLANT NUTRITION DEPARTMENT

Causes of yield variation

Comparisons between sites and previous crops

Wheat following oats, barley or potatoes. The crops preceding winter wheat have caused large differences in yield in previous years. Comparisons were made of the effects of previous crop on winter wheat (cv. Avalon) at Rothamsted where three factors (sowing date, N rate and N-timing) were tested on wheat following potatoes and also on wheat following either barley or oats (see Multidisciplinary Agronomy pp. 21–27). The amounts of fertilizer N calculated to give, with soil mineral N, the same total N supply on all sites. The smaller yields after barley were again almost certainly due to take-all. Most of the N supply until March came from the soil which, as expected, contained more NO_3-N in early spring after potatoes than after oats. Grain yields at maturity were similar, and best yields (10·58 t ha^{-1}) were identical after those two crops, so our 'balance method' successfully predicted the fertilizer N requirement on the two sites. Where enought N was given it was always best applied late in spring rather than early. (Widdowson and Penny; Darby and Hewitt)

Factors limiting yield of winter wheat at Rothamsted. Last year's experiment (*Rothamsted Report for 1982,* Part 1, 19–24) was repeated on a different site (Little Hoos). The variety Avalon, sown on either 15 September or 26 October, was top-dressed in spring with 180 or 250 kg N ha^{-1}. Each amount of 'Nitro-Chalk' was applied in three doses, and was applied either early or late to both sowings and in all combinations with the five other factors tested.

Until May yields differed little with previous crop, but from anthesis were larger after oats, and mean yields of grain (85% dry matter) were 9·8 t ha^{-1} after oats and 7·9 t ha^{-1} after barley. There were large benefits during winter and early spring from sowing in September instead of October, but these decreased with time. After oats the benefit from sowing in September was maintained until maturity but after barley the benefit disappeared, and at maturity mean grain yields were 0·65 t ha^{-1} larger from the October-sown crop. From anthesis, yields were always larger with the larger amount of N. Timing of N application never affected yields of October-sown wheat, but grain yields were larger with N applied late on September-sown wheat. The familiar positive interaction between N rate and summer fungicide was repeated and the largest yield in the experiment from a combination of three factors, (10·3 t ha^{-1}) came from applying 250 kg N ha^{-1} and summer fungicide to wheat grown after oats. (Widdowson and Penny; Darby and Hewitt)

Off-station experiments on heavy soils. Experiments with winter wheat were again made at Saxmundham in Suffolk and on the same private farms as in 1982. These tested a combined treatment of fungicides and systemic insecticides with five levels of nitrogen fertilizer. On the private farms 50 kg N ha^{-1} as urea applied at the beginning of March were also tested. At Saxmundham the nitrogen was applied either singly or as a divided dressing, on two varieties and following two different previous crops. The rates of nitrogen were designed to give the largest yield at the third level of N (in the absence of urea applied early) based on previous cropping and soil analysis for mineral N, and mostly achieved this aim.

Unlike previous years, dry matter continued to accumulate at all sites at an appreciable rate until senescence terminated growth, giving large maximum dry matter yields of 18·5 t ha^{-1} at Hexton, 17·3 at Billington, 14·4 at Maulden and 17·7 and 16·1 t ha^{-1} following beans and wheat respectively at Saxmundham. Norman and

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Avalon accumulated similar amounts of dry matter following beans, but Norman accumulated 2 t ha^{-1} more than Avalon following wheat. Applying additional N early significantly increased grain yield at Hexton and Maulden by 0·34 and 0.64 t ha^{-1}. respectively. The combined fungicide and aphicide treatments gave responses ranging from 1·09 t grain ha^{-1} at Billington to 0·35 t ha^{-1} at Maulden. The best combination of treatments produced grain yields of 11·56 and 10·21 t ha^{-1} (mean of two varieties) after beans and after wheat respectively at Saxmundham, 10·07 t ha^{-1} at Billington, 9·58 t ha^{-1} at Hexton and 8·12 t ha^{-1} at Maulden. The results confirm our ability to get high yields consistently on a wide range of soils, except on the Hanslope series at Maulden. The reason is being investigated. (Widdowson; Darby, Hewitt and Penny)

The effect of soil physical conditions on the growth of winter wheat

Effect of soil pan. Most of our winter wheat Yield Variation trial crops have yielded very well on soils with no obvious detrimental factor. However, impeded root growth caused by a plough pan was observed on the sandy-loam Cottenham series soil at Woburn in 1981. Strips at the site were either cultivated with a Wye Double Digger or ploughed; double-digging completely disrupted the pan giving low penetrometer resistances and bulk densities less than 1·50 g cm^{-3}.

Winter wheat (cv. Avalon) was sown in September 1982. The crop in the double-dug soil grew well and by the end of February had a shoot weight of 81 g m^{-2}. In contrast, the crop on the panned soil developed N-deficiency symptoms; by early December it contained only 2·5% N, compared with 4·1% for the other crop, and from then until the end of February its leaf area declined and its shoot weight stayed constant at 40 g m^{-2}.

The cause of these differences was almost certainly inaccessibility of mineral N below the pan. In November only 10·5 kg ha^{-1} of mineral N was above the pan, although both soils had totals of 65–70 kg ha^{-1} to 1 m depth. In November all roots were still above the pan, although on the double-dug plots some had penetrated to 1·15 m depth. By the end of February the crop in double-dug soil had 8·1 km m^{-2} of roots penetrating to 1·4 m depth whereas in the panned soil the 6·1 km m^{-2} of roots were only in the top 0·4 m. Root plant ratios were 0·37 and 0·52 respectively. However, after the crops had received a spring dressing of N fertilizer they both grew rapidly. By anthesis there were only small differences in root length and distribution, root weight, leaf area index and shoot weight. Final grain yields of 9·3 (double-dug plots) and 8·9 t ha^{-1} (85% DM) show how well a wheat crop can recover from a very disadvantageous situation in winter. The question remains how strong a soil pan has got to be, and in which weather conditions, before more obvious and permanent damage is done to the wheat. Other crops are likely to suffer more, and will be tested. (Weir and Barraclough; Ashton, Doran, Green and Kent)

Droughting experiments with fixed or mobile shelters. The effects of drought on the growth of Avalon winter wheat in Cottenham series soil was studied using plastic tunnel greenhouses to shelter the crops from rain. The very wet spring made pre-anthesis droughting incomplete, but unirrigated crops grew on stored soil water from early June until Harvest. Astonishingly, both droughted and irrigated crops yielded 9·2 t ha^{-1} of grain. Disrupting the plough pan made no difference to the amount of stored water extracted, presumably because by anthesis sufficient roots had penetrated the undisturbed pan. (Weir and Barraclough; Ashton, Doran, Green, Kent and Smith)

Work is well advanced on a crop shelter that combines the lightness and cheapness of a plastic tunnel greenhouse with the mobility of the large permanent installation at Rothamsted (*Rothamsted Report for 1974,* Part 1, 202). The hoops of the tunnel are attached to a wheeled carriage that runs on a steel track. The shelter is driven by an

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electric motor that is switched on and off by a rain sensor. Thus an experimental crop can be covered to exclude rain, but at other times receives full radiation at ambient temperatures and humidities. The shelter can be broken down into components light enough to be handled, and easily moved and reassembled. This year it is being tested on a wheat crop at Rothamsted; later it is hoped to use such shelters on experiments in which water supply interacts with other factors in the soil, e.g. compaction or nitrogen supply, and to make direct estimates of available water in the soil. (Weir; with Edwards Engineering and Maintenance Services)

Winter wheat crop model

The model previously described (*Rothamsted Report for 1982,* Part 1, 259) has been developed and improved further. The program has been transferred to run on the VAX computer and the root submodel, originally developed by Bragg at the AFRC Letcombe Laboratory, modified and incorporated into the main program. New modifications to leaf appearance rate, size and duration have improved the simulation of leaf canopies with different sowing dates, and the apical development submodel has been adapted to simulate the growth of cv. Avalon. A growth modifier to reduce tiller and leaf growth when carbon is limiting has been introduced, and the period of ear growth shortened. (Rayner and Weir; Parry with W. Day and J. R. Porter, LARS, and E. J. M. Kirby, PBI)

Simulating the growth of N-deficient wheat crops. Measurements of leaf area on Avalon wheat crops at Brooms Barn in 1981/82 have been used for computer simulations of crops with different levels of N nutrition. A change in applied N from 330 to 90 kg ha^{-1} reduced leaf area duration by 43%. Shortage of N greatly reduced the total dry matter produced and the number of grains m^{-2}, but hardly affected the average growth rate of the grains. The model simulated well the reduction in total dry matter and maximum rates of growth of shoots and grains, but over-estimated grain numbers on N-deficient crops and did not predict an observed check to the start of rapid growth in April. These results indicate that the full simulation model should include the effects of limited N supply on canopy size, grain numbers and photosynthetic efficiency of dry matter production (Rayner and Weir; Sastry, with Biscoe and Willington, Brooms Barn)

Simulating the growth of wheat at diverse sites. Crops of Avalon wheat were specially grown at eight Experimental Husbandry Farms and three other sites in 1981–82 and extensively monitored so that they could be used to test the crop model. Computer simulations were made using observed leaf areas and standard meteorological data from the sites. For sowing dates varying from 17 September to 10 November 1981, simulation of growth stage was good up to Zadoks growth stage 30/31, but less precise at anthesis. The simulations overestimated grain numbers by about 12%, but underestimated maximum dry matter production by about 10%, and grain yields by 16%. This study, which is to continue for two more seasons, will show how successful the model is under a wide range of conditions. (Weir; Sastry with W. Day, LARS, and L. V. Vaidyanathan and R. S. Bradley, ADAS)

Nitrogen changes in soil and crops

Effects of applied inorganic N on the supply of inorganic N from the soil. It has often been observed that increasing amounts of ^{15}N-labelled fertilizer apparently increase the uptake by crops of unlabelled soil N. This has led to the suggestion that applied mineral

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N increases mineralization of soil organic N, a so-called 'priming effect'. A simulation model for N uptake by crops was developed taking into account mineralization, immobilization and denitrification, but without assuming a priming effect.

Predicted and actual crop uptake of unlabelled soil-derived N and fertilizer N differed by less than 9%. Labelled fertilizer N stood proxy for unlabelled soil N that otherwise would have been immobilized or dentrified, and there is no need to postulate that added mineral N increased the quantity of N released by the soil. (Jenkinson and Rayner; Hart and Parry)

Loss of N in autumn. Fertilizer N not taken up by the crop to which it was applied may remain in soil at harvest and be available to a succeeding crop, together with nitrogen mineralized from soil organic matter after harvest. Such N and any autumn fertilizer dressing is at risk of loss during the winter but autumn sown crops may be able to use some part of it.

In autumn 1981, 50 kg N ha^{-1} as potassium nitrate labelled with ^{15}N, was applied to three wheat cops which also received 144 kg N ha^{-1} unlabelled N in spring. At harvest the crops contained 16%, 42% and 11% of the autumn N at Rothamsted, Saxmundham and Woburn respectively. In crop plus soil (0–50 cm) the corresponding values were 39%, 61% and 22%, suggesting that between 10 and 20% of the N had been immobilized in soil. Differences between sites may have been due, in part, to differences in soil moisture deficit in autumn when the fertilizer was applied; the deficit was least at Woburn and largest at Saxmundham. Recovery of autumn N was the same whether applied as potassium or ammonium nitrate. (Jenkinson and Powlson; Gregory, Hart, Johnston, Macdonald and Pruden)

To distinguish between losses of N due to leaching and losses to the atmosphere by denitrification, ^{36}Cl and ^{15}N were applied simultaneously in December 1982. Very similar fractions (40% Cl, 44% NO_3-N) were recovered in crop plus soil (to 70 cm) in March 1983, which suggests that in the December–March period Cl and NO_3 were lost by leaching and there was little loss of NO_3 by denitrification (Jenkinson and Rodgers; Powlson and Pruden)

Loss of spring-applied N. When N is applied to winter wheat in spring, soils are at or near field capacity and there is a risk of loss. Losses of N applied as ^{15}N-labelled NH_4NO_3 at Rothamsted, Saxmundham and Woburn were very dependent on rainfall in the period immediately following application. After the dry spring of 1982 recoveries were very high and similar at all sites, with up to 73% in the crop, and at least 87% in crop plus soil (to 23 cm). Following the wetter spring of 1981 losses were greater and differed between sites. The greatest loss (38%) was at Saxmundham where 77 mm of rain fell in the week after application, and some loss may have been via the drains. In 1983, following an exceptionally wet spring, the overall loss from the crop/soil system at Rothamsted was 30%.

Surprisingly, the results for Woburn and Saxmundham agreed well with the linear relationship between loss of fertilizer N and rainfall in the four-week period following application established for sites at Rothamsted (*Rothamsted Report for 1982,* Part 1, 263). The relationship suggests that about 8% of the applied N is lost for each 25 mm of rain which falls in the four week period following application. If it is fully confirmed, such a relationship will be of great value in determining losses of applied fertilizer N, and hence whether there is any value in remedial late top dressings on any site. (Jenkinson and Powlson; Gregory, Hart, Johnston, Macdonald and Pruden)

NO_3-N in wheat stems. The NO_3-N content of wheat stems may be a useful indication

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of plant nitrogen status. In all wheat experiments it was measured at fortnightly intervals from the end of February to mid-July. Initial concentrations in unfertilized wheat ranged between 700 and 900 $\mu g\ g^{-1}$ on all experiments except the sandy loam at Woburn, where only 60 $\mu g\ g^{-1}$ were present. NO_3-N concentrations had declined to zero by 6 May on all experiments except Billington which reached zero on 3 June. The application of N fertilizer increased stem NO_3^- concentration and maintained measurable amounts of NO_3^- until 17 June on clay loam at Woburn, 1 July on sandy loam at Woburn and at Maulden and until the final sampling on 15 July at Billington and Hexton. As before, these values were related to mineral N in soils, which were measured as in previous years. (Widdowson; Bird and Darby)

Effect of take-all (*Gaeumannomyces graminis* var. *tritici*) on the nitrogen requirement of a bread making (Avalon) and a feeding wheat (Norman). In 1982 and 1983 we investigated the relationship between the amounts of soil mineral N found under first and second crops of two wheat cultivars during winter and their responses to nitrogen fertilizer in spring, using the rotation: beans, wheat, wheat at Saxmundham.

Total dry matter yields in July 1982 and 1983 were smaller after wheat than after beans, even though more N fertilizer had been given. The disparity was greater with Avalon than with Norman. The second crop of Avalon was much more severely attacked by take-all than the second crop of Norman. Thus in both years the advantage of Norman over Avalon was small as a first, but large as a second wheat, when the mean loss from growing Avalon was 2·22 t ha^{-1} of grain, most of which can be attributed to the effects of take-all. Estimates of eyespot showed that second wheats were more severely attacked than first wheats, but there were no consistent differences between the varieties. This is the first report of differential sensitivity of a cultivar to take-all. It may have considerable implications for plant breeding. (Widdowson and Penny; Darby and Hewitt, with Gutteridge, Plant Pathology)

Nitrogen prediction system

Improvements of only a few percentage points in the efficiency of with which N fertilizer is used represents a saving of many millions of pounds each year. Recently a number of systems have been suggested for predicting more accurately the amount of N required in spring by winter wheat. Information required by such a system might include the amount of N taken up by a crop of any predicted size, and an efficiency factor to convert this into a N fertilizer dressing, which would then be modified by the amount of N in soil in spring. The latter (N min) could be determined by soil sampling, but this is time- and labour-intensive, and unlikely to be cost effective. Computer-based prediction would be much cheaper, and a model is being developed to do this from a knowledge of mineral N in soil in autumn, and temperature and rainfall thoughout winter and spring (*Rothamsted Report for 1982,* Part 1, 261). Recent work has been towards development, field testing and validation of the model using four years data from Rothamsted experiments and ADAS's 1982 experimental data. For 39 field comparisons the regression of measured on predicted N to 90 cm was not significantly different from unity and accounted for 86% of the variance. (Addiscott and Whitmore; Thomas)

Soil organic matter and biomass

Soil microbial biomass, the living part of soil organic matter, is a particularly labile fraction and as such is a sensitive indicator of change. It is also the store of some readily available plant nutrients. Current work is on nitrogen and phosphorus in biomass and the effects of heavy metal toxicity.

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Phosphorus in the soil microbial biomass. Biomass C and P were measured in 23 soils (arable, grassland and woodland) given either no fertilizer, inorganic fertilizer or organic manures. Biomass C/P ratios ranged from 10·4 to 35·7 giving a mean percentage P in the soil biomass of 2·9±0·98. Neither P concentration in the soil biomass, nor the amount of biomass P in soil, were correlated with the amount of P extracted by 0·5 M-$NaHCO_3$ solution, the reagent currently used to characterize the P status of soils. The calculated mean annual flux of P through the biomass in the grassland soils was 23 kg P ha^{-1} per year, more than three times that through six arable soils (7 kg P ha^{-1} per year). Further work is required to determine how much of this P is available to plants. About 3% of the total soil organic P in arable soils was in biomass and up to 25% in the grassland soils. The decline in biomass P when an old grassland soil was put into arable accounted for most of the decline in total soil organic P during this period. (Jenkinson and Brookes; Gregory, Powlson and Sills)

Effects of metal toxicity. The long-term effect of heavy metal additions on the fertility of soils has given cause for concern. In 1983, arable soils previously treated with metal-contaminated sewage sludge contained about half as much microbial biomass as similar soils receiving farmyard manure over the same period, even though the last applications were more than 20 years ago. Similarly, grassland soils from Luddington Experimental Husbandry Farm, treated with Cu- or Ni-contaminated sludges, contained much less biomass than similar soils treated with metal-free sludges or inorganic fertilizers. We believe this is the first report of the effects of sludge-induced metal-toxicity on the entire soil microbiological population. The consequences require further investigation. (Brookes and McGrath; Gregory, Hellon and Sills)

Measuring N in soil microbial biomass. By analogy with biomass carbon (Jenkinson, D. S. & Powlson, D. S., *Soil Biology and Biochemistry* (1976) **8,** 209–213), biomass N can be calculated from the relationship $B_N=F_N/k_N$, where B_N is N in the microbial biomass, F_N is the (measured) flush of mineral N released when a fumigated soil is incubated and k_N is the fraction of the killed biomass N mineralized under standard incubation conditions. A value of 0·68 is proposed, based on the relationship $k_N=\beta k_c/\alpha w$, where β is a weighted C/N ratio for soil microbial biomass (=6·7), k_c the fraction of the killed biomass C mineralized under standard incubation conditions (=0·45) and αw is the ratio F_c/F_N, empirically found to be 4·45. F_c is the *extra* CO_2-C released when soil is fumigated. (Jenkinson)

The effect of straw incorporation on the growth and nitrogen uptake of winter wheat

If straw burning is banned or severely restricted, its incorporation into soil may be one of only a very few viable alternatives for its disposal. A major effect of incorporation will be on the nitrogen cycle, N being immobilized in autumn and then possibly released in spring or later.

Immobilization of N in autumn. Chopped straw (3 t DM ha^{-1}) was incorporated into surface soil at the time of drilling and 50 kg N ha^{-1} as ^{15}N-labelled potassium nitrate was applied to plots with and without straw after the crop had emerged to plots with and without straw. Unlabelled fertilizer (150 kg N ha^{-1}) was applied in spring.

Straw incorporation had little effect on crop yield or uptake of N. Grain yield was 10·5 t ha^{-1} with straw and 10·8 t ha^{-1} without straw. Crop recovery of autumn applied ^{15}N was 40% with straw and 34% without, so that the straw did not compete with the crop for the autumn-applied N. The amount of straw added, of C/N ratio 78, would be expected to immobilize about 25 kg N ha^{-1}. Straw incorporation only increased the

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amount of labelled N immobilized in the soil from 2·3 to 6·0 kg ha^{-1}. The additional demand was therefore met by immobilization of some 20 kg N ha^{-1} unlabelled mineral N present in the soil in autumn. In the absence of straw this N would probably have been lost by leaching during winter.

Release of N from incorporated straw. Straw containing 15 kg ha^{-1} N labelled with ^{15}N was incorporated as described above with 50 kg ha^{-1}unlabelled N. At harvest the wheat crop contained only 12% of the straw N, whilst 78% was still in the soil. Thus only a small fraction of the N immobilized in soil by incorporating straw will be released in any one year, but cumulative effects of repeated straw incorporation may become appreciable. (Jenkinson and Powlson; Gregory, Macdonald and Pruden)

Root studies

Growth of root hairs in nutrient solutions. The effect of nutrient solution composition on the growth of root hairs of winter wheat has been studied because of their probable importance in water and nutrient uptake. Root hair length varied with nutrient solution dilution but the relationship depended upon the nitrogen source (NH_4^+ or NO_3^-) and pH. A linear relationship was found between calcium concentration and root hair length over the range 3×10^{-5} to 4×10^{-3} M calcium. The relationship between nitrate concentration and root hair length was more complex and was pH-dependent. (Leigh; Ewens)

The pathway of water flow across roots. A comparison has been made between the hydraulic conductivity of individual cell types of winter wheat roots and the hydraulic conductivity of the whole root. The hydraulic conductivity of the cells was measured using the miniaturized pressure probe. (*Rothamsted Report for 1982,* Part 1, 267) and that of the roots using an osmotically induced backflow technique. Using a simple model in which the root was assumed to consist of a series of concentric membranes, the hydraulic conductivity for water flow across the root was calculated assuming various pathways. However, the measured whole root hydraulic conductivity depended on root pre-treatment. Values obtained 1 h after excision were consistent with a single resistance to water flow located at the endodermis, but after 15 h a vacuole-to-vacuole pathway from the epidermis to the stele could explain the results. (Leigh with H. Jones, A. D. Tomos and R. G. Wyn Jones, U.C.N.W. Bangor)

Root growth and thermal time. Root lengths and weights in winter wheat crops were measured in 1980 and 1981, and were found to be linearly related to accumulated thermal time (air temperature, base 0°C). In the case of root length a single relationship fitted the data from both years [root length (km m^{-2})=0·0185 accumulated thermal time (°C days) −8·83, r^2=0·88]. This equation also fitted previously published data from, Woburn and Nottingham, and may provide a general description of root growth rates with time. Winter wheat roots generally have distinct winter and spring extension rates (Gregory *et al., Journal of Agricultural Science, Cambridge* (1978), **91,** 91–102) but by plotting rooting depth against accumulated thermal time a single extension rate for the January–June period of 1·8 mm per °C day was obtained. (Barraclough and Leigh)

Plant composition and nutrient uptake

Composition of potassium-deficient crops and osmotic pressure regulation. Previous work has shown that the concentration of potassium in tissue water was much lower in

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potassium-deficient barley crops than in those given adequate K (*Rothamsted Report for 1982,* Part 1, 266–267). However, potassium-deficient barley crops from the Hoosfield experiment had sodium concentrations up to ten times higher than those in potassium-sufficient crops, whilst calcium concentrations doubled, and this could compensate for the lowered potassium in terms of osmotic pressure.

The effect of potassium and sodium concentrations in the soil on the cation composition of barley was investigated in a pot experiment in the glasshouse. Sandy loam soils with differing amounts of exchangeable K were mixed to give a range of potassium concentrations (30–180 mg kg^{-1}) to which four levels of sodium were added. As soil potassium concentration decreased, the concentration of potassium in the barley also declined. In the absence of added sodium, magnesium was only slightly increased and the plants compensated for lack of K by accumulating sodium and calcium in equal amounts, as found in barley grown in the field. In contrast, with 80 mg kg^{-1} sodium, all compensation was with this ion, calcium and magnesium being unaffected. This suggests that sodium is preferentially absorbed to replace potassium, but when it is less available, calcium is also used as an osmotic regulator in the vacuole. (Leigh and Johnston; Packer and Wake)

Potassium in soils

Potassium reserves in some Amazonian soils. The strongly weathered soils of the Amazonian region of South America apparently contain little or no 2:1 clay minerals. If this is correct, no non-exchangeable reserves of potassium should be present in the inorganic fraction of the soil. In some Amazonian soils small amounts of total K, well above the exchangeable K content, were found. X-ray diffraction measurements detected only trace amounts of 2:1 minerals, but differential enthalpies of exchange, measured by calorimetry, identified 1–2% hydrous mica in all the soils, which could contain all of the K measured by chemical methods. These results suggest that the clay fraction of tropical soils may act as a more important potassium reserve than previously realized, and that calorimetry may be a useful tool for measuring this. (Goulding; with Dr J. C. Hughes, Department of Soil Science, University of Reading, and Dr D. B. Arkcoll, Instituto Nacional de Pisquisa de Amazonia, Brazil)

Measuring soil potassium reserves. A method to measure soil potassium reserves quickly and to estimate their availability to crops would be very useful. The Ca-resin method (*Rothamsted Report for 1982,* Part 1, 265–266) is too lengthy and complex to be used for routine analysis. Despite the initial promise shown by the simple and quick HCl-reflux method (*Rothamsted Report for 1982,* Part 1, 266), this does not predict K availability, but rather estimates the entire available reserves of K. Further attempts are therefore being made to develop a method that meets all the requirements. Tests on the use of a peristaltic pump and fraction collector to facilitate the slow leaching of soils with dilute HCl have been promising. (Goulding; Howe, with Catherine Davis, Sandwich student)

Micronutrients in soils and crops

Large amounts of some metals can be toxic, such as zinc, copper and nickel which are often major contaminants of sewage sludges, and their availability in sludge-treated soils may determine acceptable sludge loadings. Our understanding of the behaviour of micronutrients in soils depends on a knowledge of the speciation of these elements, i.e. whether they exist as free metal ions or as organic complexes, and in the solid phase or in solution. The abundance of any one form can vary with soil texture, pH, organic matter, sesquioxide content and other factors.

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Experimental and theoretical methods for determining metal ion concentrations. Analytical techniques do not exist for determining all metal species in solution, but computer models of speciation (e.g. 'Geochem') are becoming widely used for this purpose. Measurements on solutions containing combinations of Cu, Zn, Mn and Cd and the ligands citrate, glycine, salicylate and nitrilotriacetate in $Ca(NO_3)_2$ or KNO_3 used Cu and Cd ion electrodes and an ion exchange equilibrium technique, and these agreed closely in every case, but they did not always agree with the model calculations. However, the errors could be removed by substituting other published stability constants rather than those given in the model. This work will now be extended to compare measured and computer predictions for metal ion concentrations in soil solutions. (Sanders and McGrath; Hellon with S. H. Laurie and N. P. Tancock, Leicester Polytechnic)

Chemistry of zinc, copper and nickel in sewage sludges and sludge-treated soils. Results from desorption and adsorption experiments have been compared to test the reversibility of retention of metal in sludges. In the desorption experiments, Zn, Cu and Ni-contaminated sludges from sewage works were equilibrated with dilute salt solutions and the metal released to solution determined (*Rothamsted Report for 1982,* Part 1, 268). In the adsorption experiments, solutions of Zn, Cu or Ni chlorides were equilibrated with an uncontaminated sludge (to produce a 'spiked' sludge) and the metal remaining in solution was determined. The solution concentrations of all three metals were always larger in the adsorption experiments, suggesting that much of the metal in contaminated sludges is held by different mechanisms to that in spiked sludges. Hence results from experiments on spiked sludges may not be used to indicate how real contaminated sludges behave. (Adams; Brunsdon and Freeman)

Concentrations of Zn, Cu and Ni in soil solution are being measured at different times in a pot experiment, with four soils of contrasted textures which are either cropped or fallowed, all having initial soil solution pH values above neutral. The soil solution pHs have decreased with time on fallowed soils, to 6·3 on the sandy loam soil (Cottenham series). Organic C concentration in all solutions are now steady after declining rapidly during the first 7 months. Metal concentrations in soil solutions took a short period to equilibrate and then, as pH declined, there was an increase in Zn and Ni concentrations in Cottenham and Zn only in the sandy Newport series. Concentrations in the heavier textured Carswell and Upton soils were much smaller and did not increase. The percentages of Zn and Ni present in all solutions as ions increased with time, whilst Cu ion concentrations were very small, nearly all Cu being in complex form. (Adams and Sanders; Brunsdon and Freeman)

Metal toxicity to plants due to past sewage sludge applications. The effects of heavy metals in sewage sludge applied more than 20 years ago in a field experiment on a sandy loam at Woburn are being evaluated by field and pot trials. In the field, yields of red beet grown in 1983 were significantly smaller where sludge had been applied, but barley yields were unaffected. However, metal concentrations in the tissues of both crops were largest on sludged plots. In a pot experiment, however, yields of both crops were less on sludged soils than on a soil receiving fertilizer only. Sludged and non-sludged soil were mixed to give a range of levels of EDTA-extractable Zn, Cu, Ni and Cd in the soils. These and the corresponding concentrations in the crops grown on them were linearly related. (McGrath; Hellon)

Micronutrient concentrations in high-yielding grain crops. Concentrations of Fe, Mn, Zn and Cu were measured in winter wheat grain from field experiments where N

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treatments gave a large range of yields, to establish whether micronutrient concentrations decrease when high yields are obtained, which may affect crop quality. On three heavy soils, micronutrient concentrations remained fairly constant with increasing yields. However, on light sandy soil concentrations of Zn and Cu decreased when yields were greater than 8 t ha^{-1} grain. (McGrath; Hellon)

Transport processes in soils

Scaling methods. The behaviour of water in soil depends on the sizes and arrangement of the pores. The variation in pore sizes over a catchment makes it difficult to estimate the flow and storage of water in the soil. However, by assuming that the pore sizes retain a permeability similarity from place to place, scaling principles can be applied to determine the behaviour of soil water. This technique has enabled successful prediction of infiltration into, and run-off from, different soils from simple measurements (*Rothamsted Report for 1979,* Part 1, 156 and *Rothamsted Report for 1980,* Part 1, 171).

This approach has now been extended to study the behaviour of water during the redistribution following infiltration. The average soil water content during this process can be estimated well from type curves in terms of scaled variables. (Youngs; Dailey)

Hydrology of mole-drained soils. Effective drainage of heavy soils depends on the existence of a macropore structure, such as that imparted during mole draining. A new experiment in collaboration with Silsoe College has been started to study the flow of water in clay soil after mole draining. Instruments including specially designed tensiometers and flow meters have been installed to measure suction, drain flow and other variables. Additionally, the hydraulic properties of the soil are being measured in the laboratory on large undisturbed soil cores from the field. Models will be developed to account for the hydrology in such situations. (Youngs; Shipway with Dr P. Leeds-Harrison, Silsoe College)

Land drainage theory. Drainage equations derived from groundwater theory are used in the design of land-drainage installations. Based on the comprehensive study of drainage equations reported in *Rothamsted Report for 1982,* Part 1, 179–180, a new simple drainage equation has been proposed, namely:

$$H_m/D=(q/K)^{1/\alpha}$$

where H_m is the maximum water-table height midway between the drain lines spaced $2D$ apart, q the steady state rainfall rate, K the hydraulic conductivity of the soil, and $\alpha=2(d/D)^{d/D}$ for $0\leq d/D\leq 0{\cdot}35$, $\alpha=1{\cdot}36$ for $d/D>0{\cdot}35$, where d is the depth of the impermeable barrier below the level of the drains. This simple equation will be useful in the analysis of falling water-tables in drained lands. (Youngs)

Modelling solute flow. Efficient and safe use of agricultural chemicals is aided by the ability to predict their movement and distribution in the soil. A model has been developed for uniform non-aggregated soils, which predicts the solute concentration profiles produced during the leaching of a surface-applied layer of a soluble material as the soil drains to field capacity. It is based on solving the dispersion equation using an approximate method of analysis, which makes it possible to obtain solutions for the complex water movements occurring during soil water redistribution. (Towner)

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Soil aeration. Soil aeration depends on the ease with which oxygen may enter the soil and carbon dioxide may escape, and on the rates of soil and root respiration. The respiration rate, measured over a period of 44 consecutive weeks after a previous kale crop, was proportional to a constant Q_{10} to the power of $T/10$, where T is the absolute temperature. Q_{10} is between 2 and 3. Readily decomposable organic matter accounted for 6·3% of the total at the start of the experiment, and this component had a half-life of 0·95 years. (Currie)

Thermal time estimates in soils. Thermal time is important in determinations of crop development rate (see p. 60) but the method of calculating thermal time is often very approximate. If air temperatures are used a sinusoidal variation between air maximum and minimum temperatures is assumed, but if it is preferred to use soil temperatures then only one value per day at 09.00 h GMT is usually available. As part of an experiment on tillage treatments and soil temperature, soil temperatures down the profile were measured at 10 min intervals throughout winter and early spring. It was found that the soil temperature wave at 50 mm depth was often far from the sinusoidal shape assumed in the usual derivation of thermal time from meteorological records. Thermal time, above a 0°C threshold, for a single day in January obtained from measurements at 10 min intervals was 0·4°C day, compared with 0·1°C day for that derived from the soil temperature at 09.00 h GMT and 0·7°C day for that derived assuming a sinusoidal temperature wave with the measured maximum and minimum soil temperatures for the day. Such differences accumulate to a significant extent, and may be important in the use of thermal times for estimating developments in the early stages of plant growth. (North; Brown with Leach, Lawlor and Parkinson, Physiology and Environmental Physics)

Soil structure

Description of soil structure. Studies on the geometry of networks of pores in soil have continued with the aim of measuring soil structure in a more exact and quantitative way. Interestingly, the concept of a distribution of spacings between features can be applied here. The spacings between planar pores in cracking clay subsoil were measured along probe lines in several directions in three dimensions. In some directions the distribution appeared to be exponential, but in general the spacings had a more complex distribution. By modelling these in three dimensions it seemed that the spacings had two components, one completely random, with a Poisson distribution, and the other strongly directional with a preferred orientation with planes aligned parallel to the contour of the land surface and dipping into the slope. (Webster; Munden and Scott)

The structural regeneration of compacted soils. Soil used for arable agriculture is almost inevitably compacted by agricultural machinery but different types of soil differ in their ability to recover. We aim to understand these differences, and so to identify soils where failure to regenerate structure poses special management problems. Soil in small field plots on Batcombe, Hamble and Evesham series was compacted by traffic in spring and the following structural changes monitored.

Compaction drastically decreased the volume of air-filled pores larger than 60 μm in all the soils, but increased the volume of micropores around 0·1 μm somewhat as a result of shear. On all soils compaction depressed plant growth in the first growing season, and caused serious loss of yield. In the second season root development was impeded but there were no measurable losses of yield.

Structure regeneration depends partly on the soil type and partly on the intensity of wetting and drying cycles. At the surface, wetting and drying are most important, and

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fractures, usually planar and parallel with the soil surface, develop in the first growing season. These are very characteristic of such compaction zones, and are clearly more vulnerable to recompaction than the original structures that resulted from cultivation. Beneath the immediate surface, however, the regenerated structure depends on soil type and its microstructure. Air enters the pore structure of the loamy soils at fairly small suctions but the clayey Evesham soil shrinks massively, with development of large (and infrequent) cracks between structural units that have little internal air-filled pore space. Structural development within soil aggregates in response to changes in water content depends in part on particle size distribution and clay content, but also on the response of bulk clay volume to change in water activity. (Newman; with Bullock and Thomasson, Soil Survey)

Soil mineralogy

The swelling of layer silicate clays when they adsorb water, and the amounts of different forms of iron oxide in soil, substantially affect the behaviour of soil in bulk; it is important therefore to be able to identify and determine them accurately. The analysis of X-ray diffraction patterns has been improved by least-squares model fitting so that the interlayer water content of clay at different relative humidities and the amounts of goethite and hematite in soil clays can be determined quantitatively.

Effect of hydration on Ca-montmorillonite structure. The information necessary to characterize interstratified clay materials is the number, type, and distribution of interlayer species and the average number of aluminosilicate layers in the stack. In principle all of these may be calculated from the basal X-ray reflections of suitably orientated samples. The calculation is simpler if the different interlayer species are arranged in a random sequence, which is likely to be true for the smectite-illite soil clays for south-east England, in which the proportion of expandable interlayers is greater than 50–60%. A computer program has been developed that allows least-squares refinement of the structural parameters to give the best fit to the entire experimental pattern. The procedure is similar to that for crystal structure determination from powder diffraction data, but includes the effects of disorder and limited particle size.

The program is being applied to the analysis of data from a calcium-montmorillonite at different relative humidities, which has interlayer species containing one, two and three planes of water molecules. Preliminary estimates indicate that the atomic coordinates are determined to within 0·01 Å, the site occupancies to 0·2 atoms, the average number of alumino-silicate layers to 0·1 layers and the interlayer separations to 0·02 Å. (Wood and Brown; Rayner)

Quantitative determination of hematite and goethite in soil clays. Red paleo-argillic horizons in soil appear to contain markedly more stable structural aggregates than other clayey horizons. Their colour is thought to be related to the proportion of hematite to goethite in the large amount of 'free' iron oxide in the soil, produced by intense weathering in climates that were warmer and wetter than now.

Identification and quantitative determination by conventional X-ray powder diffraction is often difficult. For this reason the differential X-ray diffraction method was developed, in which the diffraction patterns of the sample before and after treatment to remove iron oxides are compared. By careful specimen preparation X-ray patterns of before- and after-treatment materials have been obtained that are directly comparable. A least-squares program has been written which minimizes the differences between the intensities of the untreated clay and the sum of the intensities contributed by the patterns of the components. For a clay containing about 9% dithionite-

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extractable iron oxide, the ratio of hematite to goethite can be determined to better than ±3%. (Brown and Wood; Sills)

Pedological studies

Weathering in soils on Chalky Boulder Clay. Chalky Boulder Clay is widespread in eastern England and the Midlands. The soils on it are agriculturally important, but vary greatly, forming intricate patterns which are very difficult to map because they are usually unrelated to landscape features. These soil types differ with respect to drainage, crop responses to P and K, and possibly also to the occurrence of cereal root diseases. The differences caused by mineral weathering in seven profiles representing four soil series were measured. This showed that the oldest soils are in southern parts of the Chalky Boulder Clay outcrop; the youngest soils and those of intermediate age occur on slopes and flat surfaces everywhere. These results suggest that the broad soil distribution patterns reflect periglacial erosion during later cold stages of the Quaternary, so the intricate patterns could result from simultaneous frost disturbance. (Catt; Bateman)

Relationship between take-all distribution and soils on Chalky Boulder Clay. An ADAS aerial photograph taken in summer 1980 of a field at Little Raveley, Cambridgeshire, showed areas of poor growth subsequently related to take-all. Take-all, yield and soil type were recorded for defined areas in 1982 and 1983. The 1980 crop was the third successive wheat after barley; this was followed by beans in 1981 and wheat in 1982 and 1983. The field had a complex pattern of soil types derived from Chalky Boulder Clay and glacial gravel.

The influence of soil type was assessed by measuring depth to chalky till and the greyish mottles produced by winter waterlogging on 1 m^2 areas within the plots. In 1982 a wide range of take-all levels was found on soils with a high winter water-table, but there was very little take-all on the better drained soils, with grey mottles occurring only below 55 cm depth. In 1983 infection was only moderate, but again there was a weak overall correlation between the percentage of plants infected and the depth to grey mottles. However, the relationship did not explain the areas of poor growth in 1980, which included well and poorly drained soils. (Catt; with Slope, Plant Pathology)

Spatial variation. The conventional way of representing spatial variation in soil is as a set of contiguous disjoint parcels. In many parts of the world the boundaries between parcels are found by sampling the soil along transects, and in such surveys there is the problem of identifying all the boundaries without excessive sampling. A method for determining the sampling effort required to map soil boundaries in these circumstances has been devised. It depends on the distribution of distances between soil boundaries, which can be estimated by prior reconnaissance, and the risk of missing boundaries that can be tolerated. In all the regions so far studied the distances between boundaries follow a gamma distribution. In several instances the shape parameter of the distribution appears to be effectively 1, so that the distribution function is exponential. In these circumstances the optimal sampling strategy is a regular grid with an interval that can be determined from the simple risk equation

$$\text{Risk}=1-e^{-\lambda u}(1+\lambda u)$$

where λ is the parameter of the distribution and u is the sampling interval. If variation is anisotropic then different intervals, u, are chosen for the directions of maximum and minimum λ. More often the shape parameter is greater than 1. The optimal sampling interval then depends on the distance from each boundary as it is crossed, and can be

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found by interpolation from a risk map. The method can provide estimates of sampling effort and hence cost when contracts for soil survey are being drawn up, and may be particularly useful in overseas development projects in which transect survey would be a normal procedure. (Webster; Munden, with Dr T. M. Burgess of Schlumberger Cambridge Research)

Leaf protein

The leaf-juice press in which a horizontal annulus rotates over a wide-angled perforated cone has now been developed to run smoothly.

Destruction of β carotene in moist leaf protein by a thermostable salt-activated catalyst is faster with rape than with any of the other species tested, and slower with elder. Catalytic activity declines with age of leaf. Preparations differ in the extent to which this destruction is prevented by extracting the leaf protein with citrate EDTA or ethanol. No practically useful protective system has so far been found, apart from rigid exclusion of air. (Pirie; Minter)

Analytical

Quantitative recovery of NO_3-N in Kjeldahl digestions. Procedures currently in use for reducing nitrate so that it can be included in determinations of total N by the Kjeldahl method are inconvenient and unsuitable for digestions in heated blocks. A new method has been developed that gives quantitative recovery of NO_3-N in plants and soils. Zinc powder is added to the sample, an aqueous solution of H_2SO_4, $CrK(SO_4)_2$ and $Ti(SO_4)_2$ added, the mixture allowed to stand for an hour and the Kjeldahl digestion then carried out in the usual manner. (Jenkinson and Pruden with S. Kalembasa, Poland)

Analytical and Isotopes Sections. One hundred and eighty one thousand analyses arising from 47000 samples were done, 26% more than in 1982. Of the total, 17% were for other departments, a considerable increase on last year. (Cosimini; Fearnhead, Messer, Pope, Smith and Thompson)

Interelement effects were investigated on the Inductively Coupled Plasma Emission Spectrometer and 46 correction factors calculated and applied for the interferences of Al, Fe, Ca, Mg, Mn, Ti, on Al, Cd, Co, Cr, Cu, Fe, Mo, Ni, Pb and Zn. (Pope)

Staff and visiting workers

Brenda Messer retired in October after 35 years at Rothamsted; I. G. Wood and Margot Ewens were appointed in February and Caroline Cunliffe was appointed on a three year contract for trace element analyses of NSI soils.

N. W. Pirie was invited to Dublin for the Food Congress, G. W. Cooke visited the International Fertilizer Development Center at Muscle Shoals, Alabama, twice, attended the Seventeenth Colloquium of the International Potash Institute in Morocco and gave a course of lectures in Madrid and a paper in New Delhi at a Seminar sponsored by FAI and FAO. Newman attended two EEC Workshops in Brussels on Soil Structure Methodology, and presented a paper at an EEC Project Review in Braunschweig. R. Webster presented papers at a Working Group on Soil Information Systems in Norway, at the Cycle de Formation of the Paris School of Mines in Fontainebleau, and at the Second NATO Advanced Study Institute in Geostatistics in California. E. G. Youngs presented papers at the FAO/IAEA Symposium on Isotope and Radiation Techniques in Soil Physics and Irrigation Studies at Aix-en-Provence, and at the ASAE meeting on Advances in Infiltration in Chicago, and gave a seminar at the University of Guelph. J. H. Rayner attended a Workshop on Winter Wheat Computer Modelling in Texas.

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T. M. Adams and S. P. McGrath presented papers at a conference on Heavy Metals in the Environment at Heidelberg. T. M. Addiscott spent six months on sabbatical in the Department of Agronomy at Cornell University, and visited and lectured at other laboratories. P. C. Brookes presented a paper at the Third International Symposium on Microbial Ecology at Michigan State University, and visited other laboratories in the USA and Canada. R. A. Leigh presented papers at a Conference on Membrane Transport in Plants in Prague, and at a joint ARC/INRA meeting in Bordeaux.

D. S. Powlson visited Thailand on behalf of ODA to discuss work on acid sulphate soils. G. A. Rodgers gave a paper at a Nitrification Inhibitor Symposium in Freising-Weihenstephan, Germany. A. P. Whitmore participated in a workshop on nitrogen prediction models at the Institute for Soil Fertillity, Haren, and visited Leuven.

P. B. Tinker presented papers to the Third International Congress on Phosphorus Compounds in Brussels, to a DFG Workshop on Nutrient Dynamics in the Rhizosphere in Braunschweig, and at a ARC/INRA meeting in Bordeaux.

D. S. Jenkinson acted as Programme Secretary for the Joint ISSS (Commissions III and IV) and BSSS meeting in Reading in July.

P. B. Tinker was awarded a D.Sc. by Oxford University and R. Webster was awarded a D.Sc. by Sheffield University. J. G. Buwalda and G. V. E. Pitta were both awarded a Ph.D. by London University and a B.Sc. was awarded to J. L. Doran by Luton College of Higher Education and to A. J. Pope by Hatfield Polytechnic. G. J. T. Scott completed his studies.

Orpah Farrington changed from a visiting scientist to a research student as at 1 April, P. B. S. Hart, R. Kemp, C. J. P. Shipway, Gamin M. Wang and A. C. Wright continued their studies. We welcomed AFRC research student Firoz Amijee, and Monique G. M. Cottaar and J. F. Kragt from the Agricultural University, Wageningen, for six months.

M. A. Gnekow returned to Germany, Dr J. Hartmann to Switzerland, Dr D. D. Patra arrived from India, Dr P. G. Saffigna from Australia spent six months here funded by the Royal Society, Dr T. G. Sastry arrived from India, as part of the collaboration between IARI and Rothamsted, M. H. Shalaby, from Egypt, spent three months here and Dr K. N. Wickramsinghe returned for one year from Sri Lanka.

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Soil Microbiology Department

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