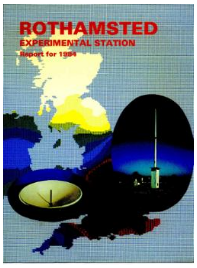
ROTHAMSTED RESEARCH

Rothamsted Experimental Station Report for 1984



Soils Division

P. B. Tinker

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INTRODUCTION

The year has seen continuing changes in the administration of the Division. The Soil Microbiology and Soils and Plant Nutrition Departments are becoming more closely integrated, including the planning of the new joint greenhouse facilities which are now being built. Much effort has been put into preparations for the move of those Letcombe Laboratory staff who are transferring to Rothamsted, and the incorporation of their research programmes into those of the Division.The first transferee to join us was welcomed near the end of 1984. The major experiments on the Letcombe sites will be continued: at Northfield studying the effects of straw incorporation and at Brimstone, the effects of land drainage, in cooperation with the Field Drainage Experimental Unit. The programme on straw integrates well with that existing in the Division, and during the year additional collaborative links on straw research have been arranged with three other AFRS Institutes and with the National Farmers Union. The traditional strength of Letcombe Laboratory in cultivation work will be continued at Rothamsted, but necessarily on a decreased scale because of job losses. This will allow us to strengthen our existing work on soil structure in the field, and to link it with the enhanced fundamental work on clay and soil structure and surface chemistry which was noted in last year's Report.

The enhanced work on clay has already shown results in a new method which allows much greater accuracy of determination of different iron oxides in clays and soils. These oxides strongly affect soil structure, and this may allow a more detailed understanding of their effect.

A most important practical test of our nitrogen prediction method, in collaboration with ADAS, has been completed successfully, and it now looks as though it can be offered to farmers when facilities for computing and data handling are made available.

The practical use of microbial inoculants of rhizobium and mycorrhizal fungi has made further progress, with successful use of pellets of seed and both inocula on upland pastures, and promising applications of mycorrhizal fungi for transplanted vegetables. The more fundamental work on nitrogen fixation has made steady progress, with the newly established techniques for measurement of carbon efficiency being applied to newly constructed rhizobium strains, which allows the effects of plasmids and chromosomal backgrounds to be separated.

Further interesting results on the control of elemental composition of plants has emerged. Earlier work explained the way in which potassium concentration in tissue water varied, but the situation for nitrogen is quite different. In barley, the concentration of nitrogen relative to tissue water never falls below a certain level—if external supply diminishes, growth slows or stops to maintain the concentration.

The new transferable mobile rain shelter has functioned very well this year, and is expected to become a valuable facility for work on soil water supply and structure problems, and in general all work needing to be done on specific soil types in which water supply is important. We now hope to modify it for DC/petrol engine power so that it is totally independent of mains electricity.

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SOIL MICROBIOLOGY

General soil microbiology

Sampling the microflora of chalk aquifers. There is uncertainty over the microbiological processes in the chalk which underlies agricultural land in much of southern England and a method was developed to allow estimation of the concentration of microorganisms in it. The bulk of chalk was dissolved in acetic acid, and the released microorganisms were stained with aniline blue and separated by centrifugation through a boundary of 40% w/v sucrose. Quantitative microscopy of stained suspensions revealed populations of *c.* 10^5 bacteria g^{-1} chalk in both the unsaturated and saturated zones. Bacteria which caused oxides of iron to precipitate were demonstrated by culture from most depths in the chalk. (Macdonald with Ms P. A. Towler, Water Research Centre)

Pseudomonads in the rhizosphere of onions. There has been a great deal of interest recently in the possibility that certain rhizosphere bacteria can promote plant growth, and a small programme on this has started. Pseudomonads have been isolated on selective media from the rhizospheres of onions growing at the Arthur Rickwood Experimental Farm. The cultures of these are being tested for plant disease suppression. (Macdonald)

Infection of *Triticum vulgare* by *Gaeumannomyces graminis* var. *tritici* (Ggt) and *Phialophora graminicola* (Pg). Ggt and Pg are two fungi which infect wheat roots, but whereas plants infected with Ggt show symptoms of take-all, growth and yield of those infected with Pg remain unaffected. The structure of *Triticum vulgare* roots infected by Ggt and Pg was examined by light and electron microscope to determine why only one fungus is pathogenic. Ggt and Pg entered the roots only in a very limited region behind the growing tip. Three-day-old roots inoculated 1 cm behind the growing tip were readily infected, but when 10-day-old roots were similarly inoculated the incidence of infection was much reduced. Early cortical death is normal in *T. vulgare* roots and partial collapse of the host cytoplasm appeared to be a prerequisite for infection. The hyphae of both fungi contained similar organelles, and mitochondria were particularly numerous. Hyphal septa were observed only where damaged hyphae were being occluded. The presence of Ggt and Pg stimulated senescing cells of the inner cortex to form lignitubers (ingrowths of the plant cell walls) which often engulf the invading hyphae. Ggt spread rapidly through the cortex and by seven days had invaded the endodermis and stele, including the central vessel, finally blocking the vascular trace. In contrast Pg infected less readily, and it did not penetrate the endodermis, though it reached the endodermis within seven days. The pathogenicity of Ggt is caused by the blockage of the vessels thus causing root death and affecting plant growth. Since cortical death is normal in wheat and Pg does not enter the stele, plant growth and yield are unaffected. (Chandler and Brown; with Hornby, Plant Pathology)

Vesicular arbuscular mycorrhizas

Approaches towards the genetics of VA mycorrhizal fungi. Work has continued to develop and improve methods for DNA extraction from VA mycorrhizal fungi, and to select for naturally-occurring strains with genetic markers such as resistance to fungicides, or heavy metal ions. The analysis of progeny from single spores will be of great interest, especially when systems for genetic modification of the fungi are developed in the future, and we have determined the optimum conditions required for obtaining plant infection with single spores.

Any introduction of genes into VA mycorrhizal fungi will need a transformation system in which the required gene is linked to cloning vector DNA with a selectable marker, typically a

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gene conferring resistance to a substance normally inhibitory to the fungus. With funding from the British Technology Group, we have screened a range of substances and determined the concentrations required to completely inhibit germination of the fungal spores on agar. (Hirsch, Spokes, Gibson and Burton)

Stimulation of hyphal growth of *Glomus caledonium*. Hyphal growth from germinated spores of *G. caledonium* was stimulated in the presence of inorganic sulphur-containing anions, particularly sulphite, metabisulphite and dithionite which all gave 10 to 20-fold increases in hyphal growth compared to that on unsupplemented agar, when supplied at the equivalent of 12 mg S l^{-1}. Other compounds—thiosulphate, sulphate, sulphide and disulphate—doubled hyphal growth, which is similar to the effect of cystine and glutathione (Hepper and Jakobsen, *Soil Biology and Biochemistry* (1983) **15,** 55–58). The largest hyphal growth response appears to be caused by anions containing at least one sulphur atom with a +4 oxidation number. The mode of action of these compounds has not yet been established, but they could be regulating the redox potential of the medium rather than acting as a source of reduced sulphur for the fungus, since no more radioactivity was incorporated into germinating spores and associated mycelium from ^{35}S-sulphite than from ^{35}S-sulphate. (Hepper)

Identification of mycorrhizal fungi. Identification of VA mycorrhizal fungi has generally been based on morphological characteristics of the resting spores and this can prove difficult at the species level. Enzyme mobility during electrophoresis has now been tested as a biochemical criterion to aid characterization. Four enzymes derived from resting spores—esterase, peptidase, malate dehydrogenase and phosphoglucomutase—can be used to identify and distinguish between six species of *Glomus*—*G. mosseae, G. caledonium, G. epigaeum, G. clarum* and two unnamed species, one from Denmark and the other previously designated type E2. Enzyme activity can also be measured in mycelium and so this method could also be used to characterize VA mycorrhizal fungi which do not produce spores. (Hepper; Sen)

Spread of mycorrhizal infection in developing root systems. There is disagreement about how to measure the extent of fungal development in mycorrhizas. Measurements of internal hyphal density have shown that all pieces of infected root in the same plant tend to have the same value, and that this uniform 'infection segment' has sharp boundaries. Infections initiated 3 cm apart on the primary root of leek rapidly increased to give a single, clearly-defined segment. Where internal hyphae from these points of infection met they did not overlap to give a higher density, suggesting that length of infected root is closely related to fungal biomass. Fertilizer P greatly increased the branching of the root system but had little effect on the length of mycorrhizal root, thus reducing the fractional infection of the whole root system. The mode of spread of infection in branched systems is being investigated. (Amijee; Stribley and Tinker)

Effect of nitrogen and phosphorus on mycorrhizal infection. Leeks inoculated with *Glomus mosseae* were grown in sand for 50 days and given nutrient solution twice weekly. Nitrate-N (1·5–12 mequiv N l^{-1}) and phosphate were supplied to give a range of N/P ratios of 2·2–70·6 in the nutrient solution. The density of infection in the roots (μg glucosamine mg^{-1} dry root tissue) decreased as the phosphate level was raised, while nitrate had the opposite effect. The amount of infection was correlated with the N/P ratio in the nutrient solution (r=0·88) up to N/P ratios >50, above which infection was constant at 1·7 μg glucosamine mg^{-1} root tissue. (Hepper; O'Shea and Sen)

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Time-course of physiological changes in mycorrhizal plants. Detailed studies of phosphorus and carbon physiology of plants have shown that effects of mycorrhizal infection are much more complex than those produced by adding P fertilizer. Mycorrhizal plants of leek grown in soil had a greater specific leaf area (leaf area/leaf dry weight), a similar leaf weight ratio (leaf weight/whole plant dry weight) and a higher rate of net photosynthesis per unit leaf area (measured on the youngest fully-expanded leaf), than did uninfected plants (given extra P) with a similar rate of growth. The mycorrhizal plants thus appeared to assimilate extra carbon yet did not grow any faster than the non-mycorrhizal plants, presumably due to a drain of carbon by the mycorrhizas. Percentage of phosphorus to dry matter varied, being initially larger in mycorrhizal plants, but subsequently lower. The reasons for the different leaf physiology in mycorrhizal plants will be investigated. (Snellgrove, Stribley and Tinker, with Lawlor and Young, Physiology and Environmental Physics)

Nitrogen fixation

Rhizobium genetics. Nine new strains of *Rhizobium* have been constructed by transferring symbiotic (Sym) plasmids into different genetic backgrounds. Recipients of plasmids can be isolated on selective media if the plasmid is marked with a transposon which confers antibiotic resistance on the host strain. We have developed a gentamicin-resistance transposon (with Dr M. Woodward, Oxford Polytechnic) which will be used in conjunction with Tn*5* (which determines kanamycin resistance) to construct new strains containing more than one introduced plasmid. A simple and reproducible method, involving *in situ* lysis of bacteria followed by electrophoresis on agarose gels, has been developed to check strains rapidly for their plasmid content. Plasmids separated in this way can be hybridized with radiolabelled *nif* DNA to demonstrate transfer of the Sym plasmid; similarly plasmids carrying a transposon can be detected by hybridization with radiolabelled transposon DNA.

Efficiency of carbon use. Work has continued on the analysis of factors controlling the quantity of N_2 fixed by legume crops. Previous techniques have been extended to use an on-stream, H_2-detecting system which allows continuous measurement of nitrogenase activity and respiration in Hup-negative strains when nitrogen is replaced with argon.

Carbon costs of nitrogen fixation (mol C used per mol electron transferred by nitrogenase) have been determined in the nodules of pea *(Pisum sativum)* inoculated with *Rhizobium leguminosarum* strains carrying the same symbiotic plasmid within different genomic backgrounds in order to locate the genetic determinants of efficiency. We have found with different genomic backgrounds containing the same plasmid that carbon costs for electron transfer ranged from 0·78 to 1·08 mol C mol^{-1} electron. These efficiencies appear to correlate with specific rates of nitrogenase activity in the nodule (mol acetylene reduced g^{-1} nodule dry weight min^{-1}) over part of the range. The background also has a significant effect in determining the time of onset of fixation. The small number of plasmids tested in these experiments all gave similar results for these parameters, although plasmid-determined differences have been found in other experiments (see *Rothamsted Report for 1983,* 167).

The cost of electron transfer and the relative efficiency (proportion of electron flux going to N_2 reduction rather than H_2 production) in pea nodules formed by strain RCR 1001 also depended upon temperature of plant growth. Carbon costs increased progressively with temperature, from 0·78 mol C mol^{-1} electron at 10°C to 1·35 at 25°C. Relative efficiency decreased from 0·53 at 10°C to 0·35 at 25°C. Broadly similar results were obtained when plants were all grown at one temperature, but assayed at the temperatures stated.

Oxygen diffusion into the nodule. Previous studies (*Rothamsted Report for 1983,* 168) show that nitrogenase activity is limited by the rate of diffusion of O_2 into the nodule, and nodules of some symbioses may rapidly alter their resistance to gaseous diffusion. Using O_2 selective micro-electrodes (4 μm tip diameter) we have demonstrated directly the response of this barrier to ambient O_2 concentrations (with Dr Niels Revsbech, Aarhus University, Denmark). Within functional nodules of pea *(Pisum sativum)* and French bean *(Phaseolus vulgaris)* exposed to a normal atmosphere the O_2 concentration sensed by the electrode in the bacteroid-containing region was less than 1 μM. When external O_2 concentrations were increased to *c.* 50% the concentration in this region increased (in 1·5 to 2·5 min) and then decreased to the former value as the barrier closed (response time *c.* 1 min). The O_2 profiles through soya bean *(Glycine max)* nodules were similar to those of pea and bean but no control mechanism could be detected. Within nodules of French bean formed by an ineffective strain of *Rhizobium* O_2 concentrations ranged from 60–100 μM and these concentrations followed those in the ambient gas phase. (Witty, Hirsch, Skøt, C. Wang, Davitt, Gibson and Khan)

Measurement of N_2 fixation by isotope dilution. Research funded by ODA to develop methods for measuring N_2 fixation in grain legumes and the rhizospheres of cereal crops continued in collaboration with International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Centro Internacional de Agricultura Tropical (CIAT). Experiments on cereals, which demonstrated much apparent fixation, were found to be affected by release of non-exchangeable $^{14}NH_4$ from the expanded vermiculite growth medium, and only small amounts of atmospheric nitrogen were fixed. Other experiments yielded contradictory results, which are presently under investigation.

Up to 40 kg N ha^{-1} (60% of plant nitrogen) was fixed in chickpeas at ICRISAT, as measured in the field by isotope dilution. The plant genotype which fixed most nitrogen had early onset and longer duration of N_2 fixation as well as higher nitrogenase (acetylene reduction) activity. Isotope dilution methods using slow-release ^{15}N-fertilizer formulations are now being used to assess *Phaseolus* genotypes produced by a breeding programme for enhanced N_2 fixation, and in particular to determine which plant characteristics give large amounts of fixed-N. (Giller; Day, Edwards and Smith)

Crop inoculation

Mycorrhizas and inoculation of transplanted onions. Onions that are raised from multi-seeded peat blocks may grow better if inoculated before transplanting into the field (see *Rothamsted Report for 1983,* 166). An experiment tested this in 1984 at Arthur Rickwood EHF on a black, alkaline fen peat soil. It was difficult to infect onions in commercial peat compost ('M64') so a modified compost was used to produce inoculated plants, though this gave smaller seedlings than did 'M64'. Seedlings were grown in modified compost with or without inoculation with *Glomus mosseae* or in 'M64' compost, and transplanted into a field factorial experiment, with or without dazomet, superphosphate (125 kg P_2O_5 ha^{-1}) and irrigation as separate factors.

Inoculation increased yields of marketable onions from transplants raised on modified compost by 94% on irrigated soil, but by only 30% on non-irrigated soil, despite a report that drought tolerance in onions is increased by mycorrhizal infection (Nelsen and Safir, *Planta* (1982) **154,** 407–413). Irrigation increased the proportion of onions that failed to bulb ('thicknecks') except on inoculated seedlings. Inoculation halved the proportion of thicknecks, and the best overall treatment was inoculation plus irrigation. Dazomet reduced all yields but did not interact with other treatments, and addition of superphosphate had no effect.

A method of infecting seedlings in 'M64' compost has now been found, and will be used in next year's experiments. (Stribley and Snellgrove)

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Mycorrhiza, *Rhizobium* and white clover in hill grasslands. Improved growth of white clover in hill grasslands by inoculation with *Rhizobium* (Mytton, *ARC Research Review* (1975) 1, 5) and mycorrhizal fungi (Hayman. 1984) has been reported. Multi-seeded pellets applied by 'strip' seeding methods to establish clover in native grass swards (*Rothamsted Report for 1983,* 167) have been tested further in 1984 with seven new trials set up in areas managed by the Welsh Plant Breeding Station (Aberystwyth), the Hill Farming Research Organisation (Penicuik), the Grasslands Research Institute (North Wyke) and the Weed Research Organisation (Yarnton).

White clover was established in slots cut in the turf, either as multi-seeded inoculum pellets or as seed with non-pelleted inoculum distributed along the slots. The pellets contained three mycorrhizal endophytes, *Rhizobium* and white clover seed. The addition of a component to help bind the ingredients together and to aid rapid drying after manufacture has improved seed viability and seedling establishment. Three of the sites have also shown up to 71% better yields from plots planted with pellets compared to those with distributed inoculum.

This year's drought adversly affected all sites and two at North Wyke and one at Yarnton have been abandoned. Despite the poor growing conditions, all the 1983 sites and the 1982 Pwllpeiran site show increased clover yield from plots inoculated with mycorrhizal fungi. All sites responded to phosphate fertilizer, but only one of the newly planted (1984) sites shows an increase due to mycorrhizal inoculum to date.

Clover roots from the 1984 HFRO and WPBS sites were all well infected with indigenous mycorrhiza early in the season. However, pellet inoculation generally increased the infection percentage. Work is continuing to identify the sites which benefit most from inoculation. (Day, Dye, Hayman; Gee, Gostick, Grace, O'Shea and Webb)

An assessment of the activity of indigenous mycorrhizal fungi is essential to understanding the response to inoculation, and may identify more efficient endophytes. The effectiveness of native mycorrhizal fungi in soil collected from the HFRO and WPBS sites was tested in the glasshouse. Two of the soils contained mycorrhizal fungi which were more efficient or more competitive than the inoculant strains. Several mycorrhizal fungi have been isolated from these soils and will be tested to establish their suitability for inoculum. (Hayman; Calvet, Estaun and Grace)

Production of moist peat-based *Rhizobium* inoculants. Inoculants for a wide range of legume crop species are now being produced by New Plant Products, a subsidiary of the Agricultural Genetics Co. Ltd, using methods developed at Rothamsted and strains from the Rothamsted collection. These inoculants are produced to meet the internationally accepted quality control standards and are marketed both locally and internationally. One major market is in southern Europe where the inoculants are used to inoculate soya beans and have given excellent results. (Jebb)

Granular inoculants. Most *Phaseolus vulgaris* seed sown in the UK is dressed with captan, making normal slurry inoculation ineffective. A field experiment in a commercial French bean field compared inoculation with a granular formulation (*Rothamsted Report for 1983,* 169) with 40 kg N applied at sowing, against the standard farm practice of 150 kg N at sowing and 50 kg N broadcast at flowering. The yield of fresh pods from inoculated plants, 13·45 t ha^{-1}, was slightly higher than the 12·32 t ha^{-1} from standard farming practice. The pods from the inoculated plants were less mature and thus commercially more acceptable (Day and Gee, with Clarke, ADAS, Eastern Region)

Staff and visiting workers

J. E. Beringer, Head of Department, resigned in March, and Margaret Brown retired after 28 years' service. Janet Why, personal secretary transferred to the Physiology and Environ-

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mental Physics Department, and D. P. Stribley and R. C. Snellgrove transferred to the Department from the Soils and Plant Nutrition Department in April. Catherine Webb, Sandwich Student, arrived in July, L. Skøt (Denmark) and C, Wang (China) continued their research and Victoria Estaun returned in August and Cinta Calvet in December to Barcelona, Spain and A. K. Podder in November to Bangladesh.

J. M. Day presented review papers in March to the First Turkish Conference on Biological Nitrogen Fixation, at Ankara, Turkey, spent three weeks in France, Rome and Bangladesh in April advising on inoculant production, chaired a session, presented a review and co-authored a research paper at the Third International Symposium on Nitrogen Fixation with Non-Legumes at Helsinki, Finland in September, attended an EEC *ad-hoc* working group in Brussels, and made two visits to Italy and France to inspect soyabean crops inoculated with NPP inoculants in June and October. K. E. Giller spent three months from January working at ICRISAT and one month in August at CIAT and presented papers at the Third International Symposium on Nitrogen Fixation with Non-Legumes in Helsinki, in September. D. S. Hayman was invited to Uruguay in November to advise on mycorrhiza in pastures, sponsored by the World Bank, and also lectured there. Penny Hirsch attended the Second International Symposium on the Molecular Genetics of the Bacteria–Plant Interaction at Ithaca, and visited laboratories in Cambridge, Mass. and at Harvard in June, and presented an invited paper to EMBO Workshop on Molecular Genetics of Nitrogen Fixation in Naples in October. D. P. Stribley presented two posters at the 6th North American Conference on Mycorrhizae, held at Bend, Oregon, in June and lectured at the University of Washington. J. F. Witty presented a plenary lecture to the 7th Australian National Legume Nodulation Conference in Sydney in January.

S. Wang returned to Brazil in December after spending four years in the Department and being awarded a Ph.D. by London University.

SOILS AND PLANT NUTRITION DEPARTMENT

Causes of yield variation

Comparison between sites and previous crops

Wheat following oats or barley was compared for a third year to complete this series of experiments (*Rothamsted Report for 1982,* 19–24, and *for 1983*, 21–25). The cultivar Avalon was sown on either 20 September or 18 October and was top-dressed in spring with 160 or 230 kg N ha^{-1} divided into three doses. The main dose was applied early (7 March) or late (3 April) to both sowings. These four factors (previous crop, sowing data, N rate, N timing) were tested in all combinations with other four factors (Multidisciplinary Agronomy, p. 23).

Mean yields of grain (85% dry matter) were 10·4 t ha^{-1} after oats and 8·2 t after barley; the smaller yields after barley were again mainly due to take-all. Early sowing had no effect on yield following oats and decreased yield following barley by 1·4 t ha^{-1}. The lack of benefit from the earlier sowing after oats in 1984 contrasts with the 1983 results. From late spring, yields were always larger with the larger amount of N. The benefit from early-applied N decreased with time and at maturity grain yields from the September sowing were larger with late-applied N, but yields from the October sowing did not differ with timing of N. The largest grain yield from a combination of three factors which included N rate and N timing was 10·9 t ha^{-1} from wheat sown after oats and given 230 kg N ha^{-1} late. (Penny and Widdowson; Darby and Hewitt)

Off-station experiments with winter wheat on heavy soils were again made at Saxmundham in Suffolk and on the same private farms as in 1983. These tested a combined treatment of fungicides and systematic insecticides, with none and 60 kg winter N ha^{-1} as urea in Febru-

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ary and five levels of 'Nitro-Chalk' in April. At Billington and Maulden the wheat followed fallow and beans respectively, at Hexton it was the fifth consecutive wheat crop. At Saxmundham the cultivars Galahad and Moulin were tested after both wheat and beans. The rates of April-applied nitrogen were calculated to be non-limiting at the next to highest rate tested (in the absence of urea applied early) by taking into account previous cropping and soil mineral N. This year however, the largest amount of April-applied N was needed for maximum yield, and at Saxmundham after wheat and at Billington with 60 kg N applied in February also.

The best combination of treatments produced grain yields of 12·79 and 11·14 t ha^{-1} (mean of two varieties) after beans and after wheat respectively at Saxmundham, 12·13 t ha^{-1} at Maulden, 10·62 t ha^{-1} at Billington and 10·18 t ha^{-1} at Hexton. Applying additional N in February had variable effects with responses up to 2·17 t ha^{-1} at Saxmundham after wheat but a loss in yield because of lodging at Hexton. The combined fungicide and aphicide treatments gave significant increases in yield ranging from 0·55 t ha^{-1} at Maulden to 1·32 t ha^{-1} at Saxmundham after wheat.

The yields in these experiments, like those obtained nationally, were larger than in previous years and we have attempted to explain them from growth measurements on the crops throughout the season. At Billington, Maulden and Hexton the rate of dry matter accumulation up to anthesis was similar to that observed in previous years. From anthesis to mid-July the rate was 20% greater than any previously recorded at Billington and Maulden. This suggests that the larger grain yields in 1984 were not because of better growth before anthesis, but reflect subsequent conditions which increased grain number per spikelet, thousand grain weight and the distribution of dry matter between grain and straw. There was less information on growth rates at Saxmundham but the components of yield suggest that increased yields were entirely due to increased numbers of ears. (Widdowson and Darby; Hewitt and Penny).

Mineral N in soils (to 90 cm). Amounts of NO_3-N and NH_4-N in six clay and one sandy soil were measured during autumn and winter under winter wheat sown following a range of preceding crops. Amounts were maximum at crop emergence in autumn, about 80–90 kg NO_3-N ha^{-1} after potatoes at Woburn, after fallow at Billington and after beans at Saxmundham and only slightly less (65 kg) after wheat at Saxmundham. At Hexton the soil had grown arable crops for 20 years and only contained 86 kg NO_3-N ha^{-1} but because the field had been long in grass before the start of the arable cropping much more N was mineralized during crop growth than the 86 kg NO_3-N would have indicated.

The earlier sowing on one experiment took up soil NO_3-N more quickly and from a greater depth than the later sowing, so that by 2 February the soils contained 24 and 51 kg NO_3-N ha^{-1} respectively. At Billington there was an almost complete loss of NO_3-N ha^{-1} between October and February (86 to 10 kg NO_3-N ha^{-1}) which could be explained only by denitrification losses following severe waterlogging. As before, little NO_3-N remained in the soils by early April. (Widdowson, Darby and Bird)

The effect of soil physical conditions on the growth of winter wheat—droughting. Results in 1983/84 from a droughting experiment using the new mobile de-mountable crop shelter (*Rothamsted Report for 1983,* 171) differed strikingly from those reported earlier (*Rothamsted Report for 1982,* Part 1, 259). In the latter, winter wheat, cv. Avalon, on a deep silty soil of Hook series grew roots to 180 cm depth and, when droughted from April to August, extracted 220 mm of stored soil water and lost only 6% of grain yield. In 1983/84 the cultivar Norman was sown into a silty clay variant of Batcombe series soil which has clay at about 40 cm. The crop grew slowly, partly because of rabbit damage, and did not put down deep roots, so that when droughted from April to August it removed only 160 mm of stored

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water from a depth of 145 cm. Compared with a crop given adequate water the droughted crop by anthesis had used 50 mm less water, and had 10% fewer ears and, subsequently, 20% fewer grains. After anthesis the droughted crop used only 40 mm of water, compared with 170 mm by the watered crop. The watered crop gave 8·7 t ha^{-1} and the droughted one 34% less.

The mobile shelter performed extremely reliably throughout the experiment, and, if it can be further modified to work with a DC motor run from rechargeable batteries, it will be possible to work on a wide range of soil types. The present 16 ft hoops however cover too small a width of soil leading to risk of infiltration of water from outside the shelter boundary. They will be replaced with 27 ft hoops, whilst retaining the basic track and carriage. (Weir, Smith and Doran; Ashton, Green and Kent)

Take-all distribution and soil type. Research is continuing in an attempt to understand the effect of soil type on the incidence of take-all (*Gaeumannomyces graminis* var. *tritici*) in wheat. By detailed mapping of the soil at one site we showed that the areas worst affected were on Ragdale series on Chalky Boulder Clay and Wickham series in valley-side slope deposits over Oxford Clay. Small patches of glacial gravel (Rockland and Acle series) and of better drained soils on the till (Hanslope and Faulkbourne series) were less affected. Together with the earlier work the results will be used to formulate recommendations for avoiding the worst effects of take-all on soils where it is likely to be most damaging. (Catt; with Gutteridge, Plant Pathology)

Winter wheat crop model

Prediction of growth stages of winter wheat. Part of the AFRS whole-crop winter wheat computer model is designed to relate the growth stages of winter wheat to day length and to daily temperature. This model can predict growth stage for any given day in a crop's growth period on the basis of weather up to the time of the prediction, followed by 'average' weather for the remainder of the season; it is under trial at a number of sites. For a crop sown in October 1983 at Long Ashton the model predicted the double ridge stage to be from four days earlier to four days later than observed, when different numbers of days of average, instead of actual, weather were used. For anthesis the range was only from one to two days late. This ability to predict growth stage allows treatments to be optimized, although the effect of these treatments will always be dependent upon subsequent weather. (Parry, Rayner and Weir with Dr J. Porter, Long Ashton Research Station)

Sub-model for soil and crop water. The model, which hitherto has simulated the growth of the healthy crops free from shortages of water or nutrients, has now been developed further to include a soil water balance and water extraction by the growing crop. The soil water model has been adapted from the CERES model developed by J. T. Ritchie, USDA, Temple, Texas, in which soil is considered as a sequence of water-bearing layers. Water removed per layer is a function of its water content and the length of roots. As available water in the profile decreases, the model simulates a decline in leaf extension rates followed by an increase in leaf senescence and a decrease in dry matter production. The enlarged model simulates quite closely the observed patterns of both water extraction with depth and time and reduction in leaf area, total dry matter and grain yield for artificially droughted crops. This, and other work reported on droughting (p. 60), emphasizes the importance of root development in determining the amount of stored soil water that can be tapped by roots, and thus the likely effect of a period of drought. (Weir and Rayner)

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Carbon and nitrogen changes in soil

Model for the turnover of organic carbon in soil. The model for the turnover of organic C in soils of the Rothamsted Classical Experiments (Jenkinson and Rayner, *Soil Science* (1977) **123,** 289–305) has been extended. It now has six compartments: decomposable plant material, resistant plant material, organisms that live on humified organic matter at a slow but fairly steady rate, microorganisms that develop rapidly when fresh organic matter is added, protected organic matter, and inert organic matter, the last containing inorganic matter assumed to have been present before soil forming processes began some 10 000 years ago.

In the model decomposition is governed by mean monthly temperature, soil moisture deficit, the cation exchange capacity (CEC) of the mineral fraction of the soil and whether or not a crop is present. The fit to data from long-term field experiments at Rothamsted and Woburn and that to results for the decomposition of labelled plant material from England, Canada, Australia, Germany and Nigeria was close, except for the Canadian examples. (Hart, Parry, Rayner and Jenkinson)

Model for the turnover of nitrogen in soil. The behaviour of soil organic nitrogen is being simulated by a model based on that for carbon described above. Three assumptions are made: that addition of fertilizer nitrogen does not increase the rate of decomposition of soil organic nitrogen, that inorganic fertilizer mixes completely with the soil inorganic pool and that in this pool it is not necessary to distinguish between ammonium and nitrate.

Nitrogen from rainfall and biological fixation, nitrogen lost by leaching and denitrification and nitrogen taken up by the crop are allowed for in simple ways. The model parameters were the same as those used to fit the C turnover process. In 1980 ^{15}N labelled fertilizer was added to a plot on Broadbalk and the fit between the measured and modelled distribution of labelled N was close, except that the decline in the predicted amount of labelled fertilizer in the crop was a little greater than observed. (Hart, Parry, Jenkinson and Rayner)

Efficient use of applied fertilizer nitrogen

Loss of spring-applied N. Previously a relationship was found between the loss of fertilizer N applied to winter wheat and rainfall in the four week period following spring application (*Rothamsted Report for 1983,* 173). However losses can also be affected by the state of the crop at the time of application and by the amount of N applied.

In April 1983, ^{15}N-labelled KNO_3 (at 206 kg N ha^{-1}) was applied to an early and a late sown crop of wheat; rainfall in the following four weeks was 73 mm. The loss of labelled N from the crop : soil system was 26% for the late sown crop, almost exactly as predicted from the rainfall, but only 5% with the early sown crop. The early sown crop was much larger than the late sown at the time of application and may have absorbed N from the soil more quickly, because of its more rapid growth and deeper root system at the time of N application.

When small (50 kg ha^{-1}) and large (206 kg ha^{-1}) dressings of labelled N were applied to late-sown wheat in April 1983 the losses were 16 and 26% respectively. This difference was probably because the smaller quantity of N was absorbed by the crop more quickly, and thus exposed to loss processes in the soil for a shorter period. (Powlson, Jenkinson and Pruden; Macdonald, M. Gregory, Sills and J. E. D. Brown)

Uptake of nitrate from depth by winter wheat. Winter wheat roots grow to, and extract water from, soil depths of at least 2 m, but little is known about how effectively these deeper roots absorb nitrate. In May 1983, ^{15}N labelled KNO_3 was applied either at the soil surface or injected at depths of 60 or 120 cm beneath late-sown winter wheat; the crop had previously received 100 kg ha^{-1} unlabelled N. Crop uptake of labelled N from 60 and 120 cm was 79%

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and 68%, respectively, of that from the surface application; thus, nitrate was absorbed effectively from depths of at least 120 cm. (Powlson, Jenkinson and Pruden; Macdonald, M. Gregory and J. E. D. Brown)

Distinguishing between nitrogen losses caused by leaching and denitrification. The proportion of N lost by these two pathways changes throughout the year, and to distinguish between them $Na^{36}Cl$ and $K^{15}NO_3$ were applied together. Leaching will remove nitrate and chloride to about the same extent from soil, but denitrification will remove only nitrate.

A mixture containing $K^{15}NO_3$ (50 kg N ha^{-1}) and $Na^{36}Cl$ was applied at four different times (1 December 1982, 7 March, 27 April and 25 May 1983) to separate plots of winter wheat at Rothamsted. At the end of the winter period, on 7 March, analyses of both crop and soil showed that both nitrate and chloride had been lost to the same extent indicating that leaching was responsible. In the next two periods ending on 27 April and 25 May, losses of ^{15}N and ^{36}Cl were small and similar. Between 25 May and final harvest 10% of the ^{15}N applied in May was lost but none of the ^{36}Cl, suggesting that some denitrification occurred during this period. (Powlson, Rodgers, Jenkinson and Pruden; Macdonald, M. Gregory and J. E. D. Brown)

Effects of dicyandiamide on recovery of fertilizer N. Delaying the nitrification of ammonium to nitrate with inhibitors like dicyandiamide (DCD) may improve the recovery of winter applied fertilizer N. Samples of winter wheat and soil (to 23 cm) were taken in March following the application of 50 kg N ha^{-1} of ^{15}N-labelled urea with and without DCD in December. Nitrogen recoveries from the urea-only treatment were 23% in the green crop and 20% in soil, and from the urea plus DCD treatment 29 and 31% respectively. For comparison, the corresponding recoveries of N applied as $K^{15}NO_3$ were 17 and 8%. The recovery of winter applied nitrogen, although small, was greater from urea than from nitrate and with DCD rather than without. (Rodgers and Pruden)

N transformations in acid tea soils. Urea, which is increasingly replacing $(NH_4)_2SO_4$ in tea plantations in Sri Lanka, may be more strongly immobilized in these acid soils than $(NH_4)_2SO_4$, making it less available to the crop. Using one such soil in the laboratory showed that for urea, $(NH_4)_2SO_4$ and KNO_3, 11·8, 11·5 and 1·8% respectively of the added N was immobilized. Very small concentrations of KNO_3 or KCl slowed nitrification in these soils, presumably because they caused a further small decrease in soil pH—typically from 4·1 to 3·8. (Rodgers and Jenkinson with Wickramasinghe (UNESCO Fellow))

Soil organic matter and biomass

Measurement of soil microbial biomass. The soil microbial biomass is the 'eye of the needle' through which all dead material passes as it is broken down to simple inorganic salts, water and CO_2. There was little fluctuation in biomass C, N or P throughout the year under continuous cereals or grassland despite the annual fluctuations in moisture, temperature and plant cover, suggesting that measurement of soil biomass content can be done at any time. A quicker method for measuring soil biomass N has been developed based on 24 h $CHCl_3$ fumigation and extraction of biomass N with 0·5 M K_2SO_4. This new method should be useful in soils receiving recent inputs of fresh substrate, e.g. straw, or in acid soils as found in many forests, for which there is currently no suitable method. (Brookes and Jenkinson; Kragt, Landman, Patra, Powlson, Pruden, Sills and Vance)

Effects of heavy metals derived from sewage-sludge on soil biomass and microbial activity. There is public concern about the disposal of heavy metal contaminated sewage sludge on agricultural land. In an experiment at Woburn, sludge was applied from 1942 to 1961 only, and now, more than 20 years after the last application, metal contents of the soils

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are still at about current maximum permitted limits. In 1983, there was only about half as much total microbial biomass in sludge-treated soils compared to those receiving farmyard manure. Fungi were decreased, but total and viable counts of bacteria, actinomycetes and protozoa were unaffected. Microbial activity was also less in the contaminated soils, as assessed by several techniques, e.g. nitrification of added NH_4-N, soil dehydrogenase activity and nitrogen fixation (by acetylene reduction). In contrast, mineralization of native soil organic N and soil phosphatase activity were unaffected. These results demonstrate the need to measure several properties when assessing the environmental effects of metal pollution on agricultural soil.

During aerobic incubation of these soils the decline in biomass was very similar both with and without heavy metals, suggesting that the longevity of the biomass was unaffected by the metals. Also there were similar responses of the biomass to added glucose in both growth and metabolism, suggesting that efficiency of biomass synthesis was unimpaired. Thus the smaller amount of biomass in the metal-contaminated soils may not be a direct effect of metal toxicity on the biomass itself. Yields of crops in the field are less on the metal-contaminated soils, so the reduced biomass may be a reflection of a smaller carbon input from crop roots, and this is being investigated. (Brookes, McGrath and Patra; with, in part, D. A. Klein and E. T. Elliot, Colorado State University, USA)

Effect of farming systems on soil organic matter and microbial biomass. The soil microbial biomass responds much more rapidly than total soil organic matter to any change in organic input. Biomass measurements are therefore valuable tools for understanding and predicting the long-term effects of changes in farming systems on soil organic matter. For example on a sandy loam soil three years of grass or grass–clover leys followed by two years of arable crops have been compared with all-arable cropping since 1937. Total soil organic C increased by a third (from 0·67 to 0·88%) with grass–clover leys but the soil microbial biomass nearly doubled. With three-year grass leys given N fertilizer, total organic C increased by 60% but biomass trebled. Straw incorporated into a loamy sand in Denmark annually for 16 years increased total soil organic C by 11% (from 1·11 to 1·24 %C), and biomass C increased by 37% and biomass N by 46%. Sorghum residues incorporated into a cracking clay soil in Queensland, Australia, for five years increased total soil organic C and N by 9% whilst biomass C and N increased by 15% and 22% respectively. (Powlson and Brookes with D. D. Patra, Sukhadia University, India, B. T. Christensen, Askov Experimental Station, Denmark and P. G. Saffigna, Griffith University, Brisbane, Australia; J. E. D. Brown and McCann)

Nitrogen prediction system

Work continued on the various models that will contribute to a more accurate system for predicting the N fertilizer requirement of winter wheat in spring (*Rothamsted Report for 1983,* 174). The full predictive system has now been tested against results from 36 field trials made by ADAS in East Anglia in 1984, and the correlation coefficient between the predicted best nitrogen dressings, and those measured by fitting a statistical model to the yield data was 0·76. The best correlations were found where wheat followed wheat or oilseed rape. (Addiscott, Darby and Whitmore)

The crop growth and N uptake model was substantially improved by simulating N uptake and dry matter production independently of each other (except when a check to one causes a check to the other). The equation used, based on the Richards flexible function (*Journal of Experimental Botany* (1959) **9,** 290–300), is:

$$Y=(A^{-1/n}+e^{-kx})^{-n}$$

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where Y is N uptake or dry matter yield, A the maximum of Y, k a rate constant, x thermal time in degree days of soil temperature, and n is a shape constant. A depends on the expected yield and n has values of 1·4 for N uptake and 1·2 for dry matter production. k is related to x' (the number of degree days to the inflection of the curve) by $k=(\ln n+\ln A)/n/x'$. For six crops at Rothamsted, x' was well related for N uptake to the number of days between sowing and the soil's return to field capacity ($r^2=0{\cdot}97$) and for dry matter to the reciprocal of the sowing-date, defined as the number of days that elapsed between 1 September and sowing ($r^2=0{\cdot}98$).

The model was developed using constants derived from Rothamsted crops, and then tested against ADAS 1982 and 1983 data; for 96 sets of observations taken from 24 sites it accounted for 88% and 93% of the variation in the nitrogen uptake and accumulation of dry matter respectively. The slopes of both regression lines were closed to unity and the intercepts non-significant. (Addiscott and Whitmore)

The leaching model has been made more relevant to heavy soils by allowing for the diversion of water and the solute it contains into field drains. The model assumes a fixed proportion of the water moving down through the soil to enter the drains. (Addiscott and Whitmore)

This improved leaching model together with the improved crop growth and N uptake model removed 84% of the variation in the soil nitrogen measured in spring on 36 clay soils in East Anglia (ADAS experiments), and 74% on 108 experiments in Hertfordshire and Bedfordshire between 1980 and 1984. (Whitmore and Addiscott; Mandeville)

Mineralization rates. Aerobic mineralization in incubated soils was measured on the 36 clay soils from the ADAS experiments and on silt soils of the Andover series. The N-fertilizer application during the crop year proved to be a fair estimator of the mineralization rate in the following autumn ($r=0{\cdot}58$, $P<0{\cdot}05$). To these mineralization data can be added similar data for Rothamsted, Woburn, Saxmundham and various farms in Bedfordshire and East Anglia to build-up a 'matrix' of mineralization rates for the N-prediction system. (Whitmore; Mandeville with Davis, Sandwich Student)

The sensitivity of the model to changes in the input variables has been investigated. Predicted available nitrogen in March is most sensitive (in descending order) to changes in the measured autumn soil N, rainfall, the water holding capacity of the soil, and the mineralization rate. For April, however, the order was rainfall, water holding capacity, autumn N, and mineralization rate. Clearly if predictions are required before the end of April accurate knowledge of winter mineralization is unlikely to be important, and a value for the rate taken from a 'matrix' based on previous cropping history and soil texture may be sufficient, until the model for N turnover in soil (p. 179) can be used to compute values. (Whitmore and Addiscott)

Root studies

Growth of root hairs in nutrient solutions. The growth response of root hairs of winter wheat to a range of factors has been determined. Root hair length responded to the concentration of ammonium or nitrate nutrient solution, and the effects varied between buffered (pH 6·5) and unbuffered solutions. In nitrate solutions growth depended mainly on pH and the concentrations of calcium and nitrate. These factors also interacted. With 12 mM nitrate buffering had little effect, with 0·24 mM hairs were about five times longer with buffering than without, and with no nitrate, hairs were about three times longer with buffering than without. There was also an interaction between all three factors, so that with

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high calcium (4 mM) and low nitrate (0·24 mM) hairs were three times longer with buffering than without and with low calcium (0·002 mM) and low nitrate hairs were nine times longer with buffering than without. Phosphate concentration did not affect the length of root hairs in wheat. (Leigh and Ewens)

Nutrient flow to roots. Little is known of the soil solution concentrations required to meet maximum nutrient uptake rates, but they can be predicted from nutrient uptake models if fluxes into roots are known. Nutrient inflows (amount absorbed per unit root length per unit time) have been calculated for high yielding (8–11 t grain ha^{-1}) crops of winter wheat grown on three soil types. Crops were either September- or October-sown and were top-dressed with N between 18 March and 23 April. The maximum nutrient uptake rates averaged over all crops were 2·75, 0·47, 3·42, 0·60 and 0·18 kg ha^{-1} for N, P, K, Ca and Mg respectively. Inflows, which reached a maximum in April or May, varied with sowing date and N applied in the range 13–34, 0·5–1·6, 3·5–13, 0·19–1·8 and 0·35–0·60$\times 10^{-14}$ mol cm^{-1} of root s^{-1} for N, P, K, Ca and Mg respectively. The concentration of each of these nutrients in the soil solution necessary to maintain inflows by diffusion through the soil was calculated from an uptake model of Baldwin *et al.* (*Plant and Soil* (1973) **38,** 621). For an October-sown crop in 1981, soil solution concentrations of 205 μM N, 15 μM P and 64 μM K were needed to maintain maximum inflows; the values were lower for a September-sown crop because it had a larger root system. Comparison of these theoretical concentrations for N and K were compared with measured soil solution values and showed that uptake of N and K by this high-yielding crop was not limited by transport through the soil. (Barraclough; Kent)

Root growth of winter oilseed rape. Because little is known about the growth and distribution of winter oilseed rape roots, soil cores were taken in May from crops which had received either no fertilizer nitrogen in the spring or 240 kg N ha^{-1} applied as a split dressing in February and April. The total length of the fibrous roots (to 1 m) on the high-N treatment was 28·3 km m^{-2}, and the fibrous root/plant weight ratio was 0·11. In contrast, total length of the fibrous roots on the low-N treatment was 17·6 km m^{-2}, whilst the root/plant ratio was 0·16. For both crops, two-thirds of the roots were in the top 20 cm of soil, although some were at 180 cm depth. The low-N crop had 90 m root g^{-1} shoot dry matter compared with 48 m g^{-1} for the high-N crop. The values for the high-N treatment are very similar to those of large winter wheat crops, and the nutrient uptake efficiency of the rape root system will be compared with that of winter wheat in future studies (Barraclough; Ashton, Doran, Green and Kent)

Plant composition and nutrient uptake

Nitrogen concentrations in spring barley. Tissue water provides a useful basis for expressing crop K concentrations (Leigh & Johnston, *Journal of Agricultural Science, Cambridge* (1983) **101,** 675–685) and expressing total-N concentrations in this way has been tested in spring barley from field experiments at Rothamsted and Woburn between 1976 and 1983. Over the range 0–150 kg fertilizer N ha^{-1} all crops when young had 8–10 g N ha^{-1} tissue water and this declined to 3–5 g kg^{-1} by anthesis and thereafter increased until harvest. When factors other than N limited growth (P, K or water) N concentrations increased compared with control crops, although their behaviour with time was still similar. The pre-anthesis decline was due to the development of stems which had lower N concentrations than leaves whilst the post-anthesis increase was due to the growth of ears which had high N concentrations. The concentrations within leaves or stems were relatively constant with time.

The behaviour of N concentrations is in contrast to those for K, which decreased in K-deficient crops, and were independent of the rate at which P, N or water were supplied

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(Leigh & Johnston, *Journal of Agricultural Science, Cambridge* (1983) **101,** 741–748). That the plant maintains a relatively strict control on N concentrations in tissue water over a wide range of nitrogen applications probably reflects the central importance of this element in metabolism. The increase in concentration in response to deficiencies of P, K and water allows it to be stored for potential use if the growth-limitation is removed. (Leigh and Johnston)

Response of barley to K deficiency. The response of crops to K deficiency has been investigated using sandy loam soils with a range of exchangeable K (40–250 mg kg^{-1}) and Na (0–80 mg kg^{-1}) contents but each containing about 1500 mg exchangeable Ca kg^{-1}. As the soil K concentration declined, growth decreased more in the absence of Na than in its presence, but crop K concentration was lower with Na than without. The decrease in yield seemed to be related to the extent to which Ca and Mg replaced K in the presence and absence of Na. Without Na, replacement was mainly with Ca and partly with Mg, whilst there were only small increases in Ca and Mg with Na. The concentrations of Ca or Mg in the crops, for all treatments, were inversely correlated with fresh weight yield (for Ca $r=-0{\cdot}975$, for Mg $r=-0{\cdot}930$). These results suggest that responses of crops to K deficiency is greatly modified by the availability and subcellular distribution of other cations (see Leigh & Wyn Jones, *New Phytologist* (1984) **97,** 1–13). (Chater, Leigh and Johnston)

Grain protein and weather factors. Protein concentration of cereal grain is more dependent on growth conditions than on variety. Responses to different husbandry treatments—especially fertilizer N—have been described previously (Benzian & Lane, *Journal of the Science of Food and Agriculture* (1981) **32,** 35–43; ibid (1982) **33,** 1063–1071). However, there is almost no published evidence from British field experiments on the influence of weather factors on grain protein. During 1957–73, for winter wheat grown with 125 kg N ha^{-1} on Rothamsted farm, temperature (June 17–July 14), which had the largest effect of all weather factors studied, was positively associated with grain protein, radiation negatively. Together they accounted for 60% of the year-to-year variance, which was 25% of the total variance. The effect of a 1° rise in mean temperature was to increase protein % (14% moisture) by 0·34. The range of temperature 1957–73 was almost 4°—equivalent to 1·4% protein. (Benzian, with Lane, Statistics)

Leaf protein. The stability of a β carotene in leaf protein has been shown to increase as the age of the crop increases.

Several improvements have been made in the juice press in which a horizontal annulus rotates over a wide-angled cone and a prototype foot-operated domestic scale juice extractor has been made. (Pirie)

Soil potassium

Mapping potassium reserves in soils of England and Wales. Together with the Soil Survey an assessment has been made of various laboratory methods to measure and then to map K reserves in soils of England and Wales. The methods were: (i) an estimate of the K contained in micaceous clay minerals (mica K), (ii) K released to a calcium resin, (iii) K extracted by leaching with M HCl and collecting sequential fractions of leachate, and (iv) K extracted by refluxing with concentrated (20% w/v) HCl.

Methods (i) and (iv) gave closely correlated estimates of K contained in micaceous soil minerals, and mica K was fairly constant within surface and subsoils of the same series derived from the same parent material. Its amount and rate of release, however, did not correlate with K removed by crops in the field. Method (iii) extracted the same amount of K

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as that exchangeable to M-ammonium acetate at pH 7, whilst allowing release curves to be constructed. The amount varied with fertilizer additions and cropping. Method (ii) extracted and distinguished between exchangeable K and fixed K (from fertilizer residues) and began to extract K from the unweathered core of soil micas. The exchangeable and fixed K, whilst correlating well with K offtake by field crops, varied with fertilizer inputs and cropping and were not characteristic of soil series.

Thus methods (ii) and (iii) predict K availability to crops, but need to be mapped on a field not a soil series basis; methods (i) and (iv) assess long-term reserves and are characteristic of soil series but do not predict short-term K availability to annual crops. An inventory of long-term reserves of K in soil series could be obtained from particle size distribution of soils, mineralogical analysis and K released under reflux with concentrated HCl. (Goulding; Howe, with P. J. Loveland, Soil Survey)

Potassium reserves in some Scottish soils. Pairs of soils from five soil series, one with a large and one with a small exchangeable K content, were analysed by methods (ii), (iii) and (iv) above and for exchangeable K. In pots, potassium uptake by ryegrass from 9–12 cuts during 18–24 months (Sinclair, *Journal of Soil Science* (1979) **30,** 775–783) was predicted best by measurements of exchangeable K. Comparing curves of K release to ryegrass and to the various laboratory extractants showed that ryegrass removed as much or more K than leaching with M HCl, but less than Ca-resin and only a small fraction of that removed by refluxing with concentrated HCl. Potassium uptake by ryegrass in pots would therefore seem to be a good predictor of short-term K reserves only (Goulding; Howe, with A. H. Sinclair, Macaulay Institute for Soil Research, and Catherine Davis, Sandwich Student)

Micronutrients in soils and crops

Attempts have continued to find good computer simulations for the speciation in soils of those metals which may be toxic to plants or animals which feed on them (*Rothamsted Report for 1983,* 178). Until this can be done, various empirical extraction procedures are used to extract metals from soil to relate to plant available metal concentrations, and two such methods are being assessed.

Chemistry of metals in sewage sludge-treated soils. The proportions of exchangeable, organically bound, oxide bound and residual fractions of metals have been determined by a chemical sequential extraction procedure on four soils which had been treated with Zn, Cu or Ni-contaminated sewage sludges (*Rothamsted Report for 1983,* 178). The proportions of exchangeable (i.e. soluble in 0·01 M $CaCl_2$) to total (sum of all fractions) metals were considerably higher in sludge treated than in untreated soils. Exchangeable metal concentrations decreased, as did soil solution concentrations, as clay content increased. The concentrations of exchangeable Cu in all soils were considerably smaller than those of Zn and Ni, because Cu was bound more strongly by organic matter.

Amounts of exchangeable metals increased rapidly as pH decreased below values of 5·8–6·5 (Zn), 4·5–5·0 (Cu) and 6·2–6·5 (Ni). At each pH value metal solubilities were related to soil texture (greatest in sandy soils) and to free Mn and Al oxide contents. These data support strongly the current guidelines on the maintenance of soil pH above 6·5 where contaminated sludges are applied and especially highlights this need on light textured soils where pH changes most quickly. (Adams and Sanders, Brunsdon and Freeman)

Metal toxicity to plants due to past sewage sludge applications. Field and laboratory experiments on the metal contaminated soils at Woburn continued (*Rothamsted Report for 1983,* 178). Yields of field-grown carrots and clover in 1984 were significantly smaller where

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sludge was applied from 1942–61 and the metal concentrations in the tissues of both crops were largest on sludged plots. The total metal contents, and the concentrations extracted by 0·05 M EDTA, in samples taken during 1960–83 have been measured to assess the long-term availability of metals. Changes in the ratio of EDTA-extractable to total metal, could be indicative of changes in the 'availability' of metals. The ratio has remained remarkably constant at approximately 50–60% for Zn, Cu, Ni, Cd and Pb during the 20 years that have elapsed since the last sludge application. These soils were also sequentially extracted by the procedure described above. Larger proportions of the metals were in the exchangeable, organic and oxide fractions in sludge-treated soils than in soils treated with FYM or inorganic fertilizers, but the distribution of metals between fractions did not change appreciably over the 20-year period. If the extractability of the metals remains at about 50% in other soils then this has important implications for the amounts of sludge that could be disposed to land. The lack of long-term changes in the chemical fractions means that the predicted 'time-bomb' effect (increasing metal extractability when the organic material decays) was not observed, but neither was the reversion to residual (and by implication unavailable) forms with time. (McGrath; Hellon)

Acid and nutrient deposition

During 1969–83, annual concentrations and depositions of major cations, and of nitrogen, sulphur and chloride in rain, and rainfall pH have been monitored at Rothamsted, Saxmundham and Woburn. At Rothamsted and Saxmundham rainfall pH has increased from about 4·5 to about 4·9; at Woburn it has not changed from about 4·5. Directly deposited acidity is thus low (0·1–0·2 kg H^+ ha^{-1} y^{-1}). Nitrification of NH_4^+ is potentially a much greater source of H^+. The 10–15 kg ha^{-1} per year of NH_4-N at present deposited could produce up to 2 kg ha^{-1} per year of H^+ ions. Large amounts of acidifying anions are deposited: 5–10, 23–35 and 50–60 kg ha^{-1} per year of NO_3-N, SO_4-S and Cl respectively. There have been increases in deposition of NO_3-N at Rothamsted and Woburn, and of SO_4-S and Cl at all three sites. Balancing cations comprise mainly Na, Ca and NH_4 with some K and Mg, but, as mentioned above, the NH_4 is potentially acidifying. The Na/Ca ratio, in equivalents, is approximately 1 at Rothamsted and Woburn but 3 at Saxmundham. Non-sea salts comprise 35% of total deposition near the coast at Saxmundham, but 58% inland at Rothamsted and Woburn. There is a significant, positive correlation of rainfall acidity and sea salts (Na, Mg, Cl) at Rothamsted and especially at Saxmundham, and a negative correlation with earth salts (K, Ca, NH_4, NO_3-N) at all three sites (Goulding and Poulton; Howe)

Transport processes in soils

Water movement to mole drains. Mole drains drawn through heavy clay soil produce a herring-bone pattern of vertical fissures with fractures fanning out at approximately 45° from the central slits made by the leg-blade of the mole-plough. By a numerical analysis of the horizontal seepage of water to the drainage channels we found that drain performance increases with increase in the length of fractures and, to a lesser extent, with decrease in the spacing of them. Typically the fracturing enables a mole-drainage system to cope with a two-fold increase in rainfall and lowers the water-table twice as fast. In a field experiment the rates of water flow from mole drains have been measured continuously after irrigation during summer and in response to rain in autumn and winter, while soil-water suctions between drains are recorded. Comparison of the hydrographs with those of a model that assumes water flow to the drains to take place via a series–parallel system of channels shows that the model describes satisfactorily the time dependence of the drain flows. (Youngs; Shipway with Dr P. Leeds-Harrison, Silsoe College)

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Modelling solute flow. The most efficient and safe use of agricultural chemicals requires the development of mathematical models to predict movement and distribution in the soil. The dispersion equation, which is often used to model such flow in homogenous non-aggregated soils, is not readily solved when the water content varies spatially. We have compared results from using mean water contents for predicting breakthrough curves for steady-state longitudinal dispersion of solute with those from a more accurate analysis in which water content is allowed to change. The error in using the mean water content can be unacceptably large when the range of water content is large or changes abruptly, and the accurate analysis should be used. (Towner)

Soil-gas transport. Soil structure can seriously affect the diffusion of gases to and from plant roots and so is important for plant growth. When soil has a bi-modal pore-size distribution, as in a seedbed, gas diffusion decreases as the soil wets in two distinct steps, corresponding to the wetting of the smaller pores within crumbs and then of the larger pores between them. When the crumbs have themselves micropedal structure, such tri-modal pore-size distribution might cause diffusion to decrease in *three* distinct steps. This speculation was tested on a system of rigid crumbs obtained by crushing blocks of Portland limestone and measuring gas diffusion on the new tri-modal packings of these stone chips. Diffusion did decrease in three steps corresponding to wetting, in order, of three modes: (1) pores within ooliths, (2) pores between the ooliths but still within the chips, and (3) pores between chips. (Currie with Dr D. A. Rose, Glasshouse Crops Research Institute)

Soil structure

Research on interparticle forces. The structural stability of a soil is determined by the balance of attractive and repulsive forces acting between its constituent particles. When an external pressure is applied to a $<2\ \mu m$ clay fraction sample, this force generates an opposing pressure to keep the particles apart. An apparatus has been constructed to measure these pressures as a function of the particle–particle distance. The effect of adsorbed phosphate on the magnitude of the forces is being studied. Experiments have begun to measure the energy involved in phosphate adsorption on the surface of the $<2\ \mu m$ fraction of these soils. The effect of adsorption will be tested by determining the aggregate size distribution, repulsive forces and shear moduli. (Piper; Sills)

Soil mineralogy

Quantitative determination of iron oxides in soil clays. The iron oxides, hematite, goethite and lepidocrocite, are important constituents in soil clays. A new method for the quantitative estimation of them by a combination of differential X-ray diffraction and profile refinement has been developed and applied to samples from buried soil horizons in South-east England. These soils had iron oxide concentrations ranging from less than 1% to 30%. The major component in all cases was goethite, which for nine of the twelve samples accounted for over 75% of the total iron oxides present. Hematite was detected in all of the soils but lepidocrocite was found in only three of them. A good correlation was found between the hematite/goethite ratio and the soil colour. This method, which allows the determination of the hematite to goethite ratio in soils containing as little as 3% iron oxide, is more sensitive and more accurate than earlier ones. (G. Brown and Wood)

Analysis of interstratified clay minerals. The interstratified clay minerals that occur widely in soils consist of alumino-silicate layers, between which interlayer material may be interposed in ordered, partially ordered or random sequences. The interpretation of X-ray diffraction patterns of such highly disordered materials is very difficult. We have developed

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a computer program for analysing patterns from randomly interstratified clays that makes interpretation both swifter and more accurate than earlier methods. The program uses least-squares refinement to obtain values of the model parameters that give the best fit between the observed and calculated diffraction patterns. We have now applied the program to patterns from the fine clay fraction of a Denchworth series subsoil in weathered Oxford clay. This sample consists of an interstratification of illite and smectite (non-expanding:expanding). The results obtained agree broadly with those previously reported using conventional methods of analysis, but correspond more closely to those expected from the chemical composition. (Wood and G. Brown; Rayner)

Pedological studies

Paleo-argillic horizons. The study of interglacial soil development on fluvial and eolian deposits in South East England was concluded. Reddened and clay-enriched buried profiles have been studied at 6 sites and have been related to period of development. The redness in the soils strongly correlates with hematite content. These results show that unburied paleo-argillic soils can be classified on their hematite content and micromorphological features in a way that reflects their geologiocal histories. (Catt and Kemp; with Bullock, Soil Survey)

Thermoluminescence dating of buried soils. The radiocarbon method is often used to date buried soils, but it over-estimates the time since burial. This source of inaccuracy can be avoided by measuring the thermoluminescence of the soil minerals, which is proportional to the time since burial. The thermoluminescence date of the A horizon of a buried loess profile agreed well with the time of burial estimated from archeological and other evidence; dates from B horizons were between those of the soil and the parent loess. (Catt; with Ann Wintle, Cambridge University)

Spatial variation. The key to understanding spatial variation in soil properties is to find a positive semi-definite covariance model to describe it and to present it as a semi-variogram. In many instances simple geostatistical functions fit the observed semi-variograms well. These increase either to maxima ('sills') at fairly clearly defined ranges or linearly and apparently indefinitely. In some instances variation in the soil appears to be nested, i.e. have more than one distinct scale. Such variation is best modelled by combinations of simple semi-variogram functions. Geometric anisotropy in the horizontal plane is common. Thus a simple transformation of the coordinates enables it to be modelled in the same way as isotropic variation. Parameters of the models are estimated by weighted non-linear least squares approximation using the Maximum Likelihood Program. (Webster; Munden)

The process by which variation is created from an initially homogeneous state is being investigated in collaboration with Silsoe College by computer modelling. A model has been developed to represent a sequence of raindrop impacts on soil, their transformation into a corona and then into droplets, and the entrainment and redistribution of soil particles in the dispersed droplets. The model has been run to simulate rain storms of intensity and duration that are common in the tropics and has produced realistic redistributions of soil. (Wright and Webster; Munden, with Dr R. P. C. Morgan and Mr D. D. V. Morgan, Silsoe College)

Studies on the spatial variability of soil nitrogen and related properties have continued with an experiment this year on Summerdells II where winter wheat followed oats. Ammonium and nitrate in the soil showed little spatial dependence at the spacings tested, but grain yield and soil moisture content produced typical transitive semi-variograms with well defined sills at a range of 30 m. The moisture release characteristic of the soil also shows spatial dependence to the same lag as crop yield and soil moisture content showing that all three vary together. (N. J. Brown; Addiscott, Mandeville, Patel, Webster and Whitmore).

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Analytical and techniques

Analytical and isotope sections. The Analytical Section did 200 000 analyses, arising from 32 000 samples, whilst the Isotope Section did 6400 analyses; of these 7 and 81% respectively were for other departments. (Cosimini, Fearnhead, Gregory, G. J. Smith, Pope and Thompson)

Inter-element effects on the Inductively Coupled Plasma Emission Spectrometer (ICPES) were further investigated and correction factors for the effects of Al, Fe, Ca, Mg, and Mn on As, Ba, P, S, Se, and Ti derived. Seventy-nine correction factors have now been derived. (Pope)

National Soils Inventory samples are now being analysed using a method that has been developed using aqua regia in tubes in a block digestor for analysis by ICPES. Problems with interference from calcium in extracts of highly calcareous soils have yet to be solved. (Cunliffe)

Data transfer system for neutron moisture meters. Software has been written for two new microprocessor-controlled neutron meters, which enable data to be recorded and transferred to the main VAX computer automatically and without error via an Epson HX-20 portable computer. (North)

Automatic data recording. At present all measurements made on the crop and soil samples (over 10 000) which pass through our sample preparation facilities are recorded by hand. A system is being developed which identifies samples from machine readable bar-coded labels, records weights automatically from electronic balances and allows other measurements to be entered by keyboard. An immediate record of each data entry is printed and the system rejects experiment and plot numbers that are not recognized, and draws attention to deviant values. All datasets can be stored on tape which are accepted by the VAX computer.

There has been some difficulty in reading barcoded labels some months after printing, or following exposure to moisture; work continues on these problems. (Darby; with Verrier and Hipgrave, Computing Unit)

New X-ray equipment. A new Philips high-stability X-ray generator capable of running two X-ray tubes simultaneously and a computer control system for one of our existing X-ray powder diffractometers has been installed and commissioned. Much new computer software for collection of data in step-scanned mode and for their later retrieval and graphical display has been written. Copies of this software have been distributed to other AFRS Institutes for use with other types of data. (Wood and G. Brown; Nicholls)

Staff and visiting workers

T. M. Adams resigned and A. C. D. Newman took premature voluntary retirement.

Kate Copestake (née Duff) was appointed on a three-year contract funded by Norsk Hydro Fertilizers for work on nitrophosphate fertilizers and P. D. Robertson transferred from Letcombe in December to join the Analytical Section.

N. W. Pirie attended a Conference on The Right to Food in Montreal in May and attended the 1st Symposium of the Kenya National Academy of Sciences in Kenya in September. G. W. Cooke visited the International Fertilizer Development Center at Muscle Shoals, Alabama in March and gave a course of lectures in Madrid in April. He also gave a paper at the 9th World Fertilizer Congress of CIEC in Hungary, attended the 18th Colloquium of the International Potash Institute at Gardone, Italy, both in June, gave a paper at the 16th Brazilian Meeting on Soil Fertility at Ilheus in July and gave a paper at a symposium on Environment and Chemicals in Agriculture in Dublin in October. At the International Soil

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Science Symposium on Solute and Water Movement in Heavy Clay Soils at Wageningen, The Netherlands in August, G. D. Towner presented a paper and chaired a session, T. M. Addiscott gave an invited paper, A. P. Whitmore presented a poster and C. P. J. Shipway gave a paper. T. M. Adams and J. R. Sanders presented a paper at an EEC Seminar on Chemical Methods for assessing Bio-available Metals in Sludges and Soils at Münster, West Germany in April. G. Brown was an invited speaker, and Jennifer Piper attended a NATO Workshop on Soil Colloids and their Association in Soil Aggregates at Ghent, Belgium in September. A. E. Johnston presented two papers and P. B. Tinker presented an invited paper at the 18th Colloquium of the International Potash Institute at Gardone, Italy in June. Dr Tinker also attended and presented invited papers at the 6th North American Mycorrhizal Conference at Bend, Oregon, USA in June. He lectured at the University of California, Berkeley and Davis, and the University of Hawaii in July. He presented a keynote paper at the Conference on Soils and Nutrition of Perennial Crops at Kuala Lumpur, Malaysia, and visited and lectured in Nanjing and Beijing, China at the invitation of the Academia Sinica. He was invited to participate in a Soil Science Symposium at Stanford University, California, in October. R. Webster visited Israel for three weeks during March to discuss spatial analysis and lectured in the Volcani Centre, Bedt Dagan, and at the Hebrew University in Rehovot. A. P. Whitmore presented a paper at a workshop of the North West European Group for Nitrogen Prediction in Haren, The Netherlands in May and I. G. Wood presented a paper at the 13th International Union of Crystallography in Hamburg, Germany in August.

R. A. Leigh departed in October for the Division of Horticultural Research, CSIRO Merbein, Australia, at the start of a six-month study leave.

I. G. Wood was appointed as an Honorary Research Assistant in Geology at University College of London. P. B. S. Hart was awarded a Ph.D. by the University of Reading, R. A. Kemp and Gamin Wang were awarded Ph.Ds by the University of London, Margaret Oliver was awarded a Ph.D. by the University of Birmingham and A. B. McBratney was awarded a Ph.D. by the University of Aberdeen.

Professor J. M. Oades from the University of Adelaide, Australia, spent a six-month sabbatical in the Department. Monique Cottaar, Andrea Landman and J. F. Kragt, all from the Agricultural University, Wageningen, returned after spending six months each with us, D. D. Patra returned to India after one year here on a Commonwealth Fellowship, T. G. Sastry returned to IARI, New Delhi in March after completing nine months studying crop modelling, K. N. Wickramsinghe returned to Sri Lanka after one year as a UNESCO Fellow, and we welcomed S. J. Kalembasa of the Agricultural and Teachers University, Siedlce, Poland for three months under the auspices of the British Council, H. Kuhlmann, of the Institute for Plant Nutrition, Hanover, West Germany for twelve months to study root growth and nutrient uptake in winter wheat, E. D. Vance, of the University of Missouri, USA, for nine months on a Fulbright-Hays Scholarship, and Kathryn Dancy of the University of East Anglia for six months working on estimation of fodder grass in African range land by remote sensing and kriging. F. Amijee and A. C. Wright continued their studies.

PUBLICATIONS

Soil Microbiology Department

Thesis

Wang, S. R. (1984) *Effect of nitrogen and other factors on plant growth responses to vesicular-arbuscular mycorrhiza.* Ph.D. Thesis, University of London.

General Papers

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Soils and Plant Nutrition Department

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