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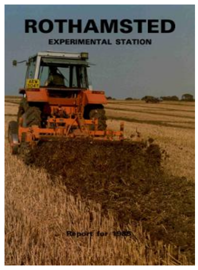

Soils Division

P. B. Tinker

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INTRODUCTION

The year was again eventful. A number of staff from the AFRC Letcombe Laboratory joined us, mostly in Soils and Plant Nutrition, but one in Soil Microbiology. Vacancies associated with the move to Rothamsted were lost in this year's staff reductions, placing heavy pressure on the Division's ability to maintain the commissioned work in the programme. A most serious blow was the decision to transfer work on nitrogen fixation to Aberystwyth, as part of an AFRC-wide reorganization. Although it is not yet known finally what the decision means for individual scientists, the result is likely to be the breakup of valuable and effective teams carrying out work on physiology and genetics of *Rhizobium*, and on the dual inoculation studies on upland clover.

The year was more promising in terms of equipment. The new glasshouses were completed and taken into use.

The work on dual inoculation of upland clover has again produced promising results, and it seems that practical application may not be far distant. For the first time we report on work related to lupins, which will receive more attention as part of the thrust into alternative crops. A new technique developed earlier for obtaining a large fraction of the soil microbial population in a viable state without culture on selective media has been used to separate a wide range of *Pseudomonas* species. This approach may have biotechnological uses. The new enzyme identification methods for vesicular-arbuscular mycorrhizal fungi has been shown to be applicable to root infections, and is now being applied to studying competition between fungal strains. Differences between *Rhizobium* produced by transferring plasmids emphasize the importance of the chromosomal background in determining the energy efficiency of fixation, and the important characteristic of early onset of fixation. Much work has been done on the measurement of N_2 fixation in the field. We report this year on the programme funded by ODA on tropical crops; improved techniques have been developed but no significant associative fixation by cereals could be found.

In succession to the Letcombe programme we have developed new work on straw disposal, with field and laboratory experiments on effects on yield, nitrogen economy, straw breakdown and other aspects. This was carried out as part of the coordinated programme of the AFRC Straw Disposal Group. Also as part of the accession of the Letcombe programme has come the Brimstone drainage experiment. This is a major investment, and will give much essential information on drainage in relation to arable crop growth, and also to leaching of nitrate and other solutes.

The continuing work on the prediction of nitrogen leaching and need was made available to farmers, in abridged form, by putting it on public viewdata systems. The ability to predict nitrate concentrations in water moving below the rooting zone is now being tested, as an aid to pollution control. Further studies on the turnover of nitrogen under wheat have been made, and have been extended to ley-arable rotations. Good recoveries of applied ^{15}N-labelled fertilizer were found. To test our earlier conclusions about loss of fertilizer N in spring by denitrification, analyses for nitrous oxide were done using the acetylene blocking technique. These showed little denitrification in spring under winter wheat, which agreed with prediction for this dry period based on our previous work.

In present circumstances the attainment of high yield is undoubtedly profitable for the individual farmer, but increased production is no longer the primary national aim. Instead, predictability, cheapness and quality are the main aims. The yield variation concept is thus still valid if it aims at predictability and stability of yield. Much of the effort is now being transferred to oilseed rape and other alternatives to cereals. To ensure that quality of crop is fully taken into account, measurement of hectolitre weights of grain was done on a routine basis this year. Percentage-N has, of course, always been measured, and more complex measurements of quality will be studied later.

Studies of nutrient uptake have developed at both the whole-plant and cellular levels. Nutrient uptake rates from solution per unit fresh weight were similar for the nodal and seminal roots of wheat, but the root radii differed, so uptakes per unit length were much larger for nodal roots. If either root system was deprived of nutrients, the other was able to absorb at a higher rate, and so allow growth to continue unhindered. A new pyrophosphate-driven proton pump has been discovered on the tonoplast of oat root cells, and this work is now aimed at understanding the processes which control the accumulation in cell vacuoles of ions, particularly nitrate. A survey of concentrations of both sulphur and micronutrients in wheat has been completed. The sulphur concentrations correlated well with known values of atmospheric deposition of SO_2, which suggests that if sulphur emissions are decreased further, deficiencies of this element could be found.

The new programme on soil and clay structure is now getting under way, with new methods of X-ray analysis of soil components, and results on the mechanical properties of soils in bulk. Soil structure is a notoriously difficult subject in which to make fundamental progress, but we believe that these new approaches will bear fruit. The use of spatial variation methods is increasing, and the work reported here shows the variety of possible applications.

This year we report finally on the large programme started four years ago to test the effects of heavy metals in sewage sludge at the request of MAFF. The general conclusion suggests that the current soil metal limits, based on EDTA-extracts, are generally satisfactory to protect against adverse effects on yield and unacceptable increases in zinc, copper and nickel concentrations in plant tissue, provided that soil pH is maintained at greater than 6 for grassland and 6·5 for arable crops. However, measurements on our long-term sludge application experiment have indicated a surprising reduction in soil microbial biomass on plots containing heavy metals; the reason is being investigated. We report also on the serious effects of heavy metals on nitrogen fixation by soil organisms. Both these observations may have implications for amounts of metal which should be added to soil.

SOIL MICROBIOLOGY

General soil microbiology

Rhizosphere pseudomonads. Soil dispersed by reaction with a chelating ion exchange resin and washed homogenized roots were cultured on a defined selective medium which excluded Gram positive bacteria and fungi. About 60% of the colonies which developed on this medium were *Pseudomonas* spp. More than 500 pure cultures of pseudomonads have been obtained and preserved by freezing at −20°C in glycerol. The cultures are being tested against target plant diseases under controlled environmental conditions; those bacteria which are most inhibitory to disease will be field tested. (Macdonald)

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Chemical and microbiological additions for straw breakdown. In a field trial wheat straw was treated with whey (15 kg ha^{-1}), with *Trichoderma harzianum* or with *Penicillium janthinellum* (106 spores g^{-1} straw). In the laboratory whey has been shown to increase the rate of straw decay and the two cellulolytic fungi were particularly effective in straw decay. However, neither whey not fungal inoculants increased rates of decay in the field. *T. harzianum* and *P. janthinellum* were detected on straw throughout the autumn but their numbers were not increased by inoculation, perhaps because in autumn 1984 numbers of *Trichoderma* were much larger than normal. Yields of grain were not affected by any of these treatments. In autumn 1985 numbers of *Trichoderma* were much lower, and inoculations markedly increased the population of the fungus. However, indications so far are that this did not accelerate decay of the straw. (Harper)

Vesicular–arbuscular mycorrhiza (VAM) fungi

Identification of VA mycorrhizal fungi in roots using biochemical criteria. Enzyme banding patterns, obtained following separation of proteins by polyacrylamide gel electrophoresis and staining for esterase, glutamate-oxaloacetate transaminase and peptidase activities, have been used to identify VA mycorrhizal fungi within their host root. The banding pattern from a mycorrhizal root extract contained bands corresponding in mobility to those found in extracts of resting spores, external mycelium and internal mycelium isolated from roots by enzymic digestion. Using this method it has been possible to detect the presence of *Glomus caledonium, Glomus fasciculatum* (E3) and *Glomus mosseae* in leek roots, and the latter two fungi in maize roots. Bands characteristic of two fungi could be seen in leek roots which had received an inoculum containing both. The method is therefore valuable for investigating fungal competition. (Hepper and Sen)

Comparison of strains. The influence of soil pH on the effectiveness of mixtures of up to four endophyte species was examined. At both pH 5 and 7, clover and strawberry plants grew at least as well with three or four fungi as with any endophyte tested singly. These results indicate good inter-endophyte compatibility and support the concept of using mixed inocula to increase the chances of successful field inoculation. The new methods of identifying endophytes in roots will allow the effects of mixed inocula to be analysed.

The production of resting spores was assessed as a measure of relative activity of different VA endophytes. *Glomus* E3 sporulated profusely at pH 5 in single culture or in combintion with up to three other VA species, whereas all the latter sporulated poorly alone and even less in mixtures. At pH 7 *Glomus mosseae* produced many spores alone and in combination with other species, whereas *Glomus* E3 sporulated poorly in competition with other endophytes. Results were the same on strawberry and white clover, indicating that endophyte growth depends more on the soil than the host plant. (Hayman; Koomen)

Host-endophyte relationships. In most plants infection by VA mycorrhizal fungi is generally reduced by high concentrations of phosphorus (P) in the soil, but the mechanism is not understood. Leeks (*Allium porrum*) were grown on γ-irradiated soil to which P had been added at levels from 0 to 750 mg kg^{-1} of soil, and were inoculated with *Glomus mosseae*.

The length of infected root per plant (Li) increased with added P up to 300 mg kg^{-1}, but larger additions of P severely and abruptly reduced it, and also numbers of entry points and vesicles. Sucrose concentrations increased with added P up to 450 mg P kg^{-1}, but then declined sharply. However, the concentrations of sugar (chiefly sucrose) were generally much higher in mycorrhizal than non-mycorrhizal plants, which does not support earlier reports that soluble carbohydrate levels control the rate of spread of the fungal endophyte. (Amijee, Stribley and Tinker)

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There have been reports that chloride concentrations in plants are raised by mycorrhizal infection, and also that chloride can inhibit take-all. The interactions of these variables was therefore investigated in a pot experiment that tested interactions between effects of a VA fungus (*Glomus mosseae*), inoculum of take-all (*Gaeumannomyces graminis*), water stress, chloride and phosphorus added to soil, on growth of spring wheat. There was no evidence that mycorrhizas improved drought tolerance or that Cl inhibited take all. *G. graminis* almost completely inhibited mycorrhizal infection in roots that bore lesions. (Stribley)

Nitrogen fixation

Efficiency of carbon use. Work has continued to locate the genetic factors controlling the carbon costs of nitrogenase activity and amounts of nitrogen fixed by *Rhizobium leguminosarum*. Three selected Sym plasmids were each introduced into three rhizobial strains (B151, JI6015 and JI8400) lacking nodulation and nitrogen fixation genes (which reside on the Sym plasmid) and the resulting strains were tested on peas. Irrespective of which plasmid was used, nodules formed by strains with the JI6015 chromosomal background had a 25% smaller carbon cost of nitrogenase activity relative to the two other backgrounds. However, a delay in the onset of fixation with these transconjugant rhizobia resulted in a lowering of N_2 fixation and hence shoot dry weight.

The Sym plasmids of two field isolates, JI300 and RCR1045 were transferred to B151 and both transconjugants produced higher shoot weights on peas than the donor strain. Efficiencies of carbon use by both parents and transconjugants were similar but the chromosomal background again had a large effect on time to onset of fixation, both transconjugants in the B151 background being early relative to the parent strain. These results demonstrate the importance of early nodulation in determining the total amount of nitrogen fixed by the legume/*Rhizobium* symbiosis and show that this is little affected by the nature of these Sym plasmids. (Skøt, Hirsch and Witty; Davitt, Gibson and Spokes).

Oxygen diffusion into the legume nodule. Previous studies (*Rothamsted Report for 1984,* 173) have shown that the nodule is bounded by a barrier to oxygen diffusion which is under rapid biological control. A dark field microscopic technique has been developed to examine air-filled pathways within the nodule which form the major routes of oxygen movement. Increases in external oxygen concentrations which are known to increase diffusion resistance resulted, within three to eight minutes, in a decrease in the frequency of interconnected pathways within the inner cortex. Work is continuing to evaluate the implications of these changes and the mechanisms responsible. (Witty and Skøt)

Measurements of N_2 fixation using ^{15}N. N_2 fixation can be measured by dilution of ^{15}N supplied in fertilizer by $^{14}N_2$ fixed. Estimates are based on the difference in ^{15}N enrichment between the fixing crop and a non-fixing reference plant. Errors may occur due to poor matching of legume and control coupled with changes in the ^{15}N-enrichment of available soil N with time. Slow release fertilizers were evaluated as a ^{15}N source for estimation of N_2 fixation by isotope dilution in a field experiment. Estimates of fixation by pea and chickpea were made using ^{15}N ammonium sulphate incorporated into soil with sucrose several months prior to the experiment to produce ^{15}N labelled soil organic matter: irrespective of whether uninoculated chickpea, barley or rape were used as reference crops, similar fixation was found. When ^{15}N ammonium sulphate alone was applied at sowing, widely differing estimates of fixation were found with the three controls, hence the former method is preferable. (Giller, Witty; Edwards and Smith)

The project funded by ODA to develop methods for measurement of N_2 fixation in grain legumes and the rhizospheres of cereal crops continued in collaboration with Centro Inter-

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nacional de Agricultura Tropical (CIAT) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). *Phaseolus* genotypes produced in a breeding programme for enhanced N_2 fixation were evaluated by isotope dilution using slow-release ^{15}N fertilizers. Advanced lines generally fixed larger amounts of nitrogen (up to 47% of plant N; 36 kg N ha^{-1}) than early parental genotypes, because they either nodulated earlier or used photosynthate in the nodules more efficiently.

Using $^{15}N_2$ enriched atmospheres it was found that the amount of fixation in the rhizospheres of young sorghum and millet plants was a small proportion (<4%) of the total N accumulated over the same period. In many cases the amount of N_2 fixation was too small to be detected (<1 μg N per plant per day). Genotypic differences in isotope dilution were too small to be detected (<5%) in experiments conducted in soil into which ^{15}N had been incorporated several months previously. This confirms earlier findings that the contribution from N_2 fixation by rhizosphere organisms of these cereals is limited. (Giller; Day, Witty, Edwards, Smith)

Crop inoculation

Mycorrhiza, *Rhizobium* and white clover in hill grasslands. These experiments were started in 1983 and 1984 (*Rothamsted Report for 1983,* 167, and *1984,* 175). Yields in 1985 were small because the growing season was cold and wet.

The crops were topped in early spring and cut for yield in July and September. Data from both the 1983 and 1984 sowings on both mineral and peaty soil in mid-Wales showed significant responses to P, and increased clover yields when VAM fungi were also included. Combined dry weight of clover from the 1984 sowing on the mineral soil were 165 kg ha^{-1} with both P and VAM fungi, 79 kg ha^{-1} with P alone and 5 kg ha^{-1} for controls; yields from the 1983 sowing were larger, 543, 353 and 88 kg ha^{-1}, respectively. The increased overall yield between the 1983 and 1984 sowings demonstrates the persistence and spread of introduced clover in these sites. Data from the peat sites showed similar responses, although yields were lower.

Phosphate increased clover yield on peaty sites in southern Scotland, sown in 1984, but inoculation with VAM fungi had no effect. There was no significant response to either P or VAM fungi on a nearby neutral soil.

These experiments have shown good clover establishment from multi-seeded inoculum pellets, including another experiment this year in mid-Wales comparing pellets of different sizes. We are now developing smaller pellets intended for machine application, and are aiming to produce more concentrated inoculum containing larger numbers of infective propagules. (Day, Dye, Hayman; Ellis, Fraser, Gee, Gostick, Grace)

***Rhizobium* numbers and liming.** *Rhizobium trifolii* from acid upland soils are often sparse or absent by classical MPN (most probable number) counting techniques. However after liming, clovers sown into these soils often nodulate profusely by the end of the first season's growth. Work has been started to study population dynamics of *R. trifolii* in response to cultivation and applications of lime and phosphate in an attempt to explain this anomaly. Changes in populations of *Rhizobium* in response to liming, especially if they occur in the soil prior to planting, could have important practical implications as lime is often applied before pastures are resown with inoculated seed. Our results to date show that liming causes rapid multiplication of *R. trifolii* from *c.* 10 g^{-1} dry soil to *c.* 10^4 g^{-1} dry soil only when white clover is present; in unplanted soil there was very little multiplication. The results are similar for both peat and mineral soils. The study is now being extended to examine the effect of grasses and brassicas on *Rhizobium* proliferation. (Dye, Ellis and Day)

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Inoculation of lupins. Lupins grown in soils with a pH above 6·5 benefit from inoculation with effective strains of *R. lupini*. However, the seed is often sold dressed with various fungicides, and the toxicity of these to *Rhizobium* has now been tested.

Seeds of *Lupinus albus* cv. Vladimir were obtained untreated and dressed with thiram ('Tripomol 80'), metalaxyl+thiabendazole ('Apron T69 SD'), drazoxolon ('Mil-col 30'), carboxin ('Mist-O-Matic Murganic RPB Liquid Seed Treatment') or gamma-HCH ('Gammasan 30'). Seeds were inoculated with peat based inoculant (NPPL) containing the commercially used strain of *R. lupini* (RCR 3211) at normal field application rates of *c.* 250 g inoculant per 100 kg seed, to give a final count of *c.* 10^6 rhizobia per seed. The inoculated seeds were air dried and stored for 24 h, before sowing in a mixture of pre-wetted sand and perlite and watered from above after three and six days. After four weeks plants from untreated seeds had 15–20 nodules on the primary root and some young secondary root nodules. Plants from 'Mil-col', 'Gammasan' and 'Apron' treated seed showed sporadic nodulation and had few nodules restricted to occasional plants. Carboxin was slightly less toxic but still reduced nodule number to 25% and nodule weight to 50% of the controls. Thiram delayed, but did not appreciably reduce nodulation with plants having fewer nodules on the primary root and more on the secondary roots. Thiram is the only fungicide tested that could be recommended if the seed is to be inoculated with *Rhizobium*. (Chandler and Day)

Staff and visiting workers

P. B. Tinker, acting Head of Department, resigned at the end of November to take up the post of Director of Terrestrial and Freshwater Science at the Natural Environment Research Council. Ruth M. Bowen was appointed in May for a New Initiative three-year appointment for work on straw breakdown, to work with S. H. T. Harper, who transferred from Letcombe to join the Department. P. M. Williams was temporarily appointed in November for 18 months by Agricultural Genetics Company and Irene Koomen was temporarily appointed to the EEC-funded research project on the joint inoculation of tropical forage legumes with strains of VA mycorrhizal fungi and rhizobia for work to be carried out at Rothamsted in collaboration with CIAT.

K. E. Giller spent two months working at CIAT, Colombia and two months at ICRISAT, India. Christine M. Hepper, Penny R. Hirsch, D. S. Hayman and P. B. Tinker all presented papers at the First European Mycorrhizae Conference, Dijon, France. D. S. Hayman gave a training course in Egypt. He presented an invited paper at the Seventh International Conference on Global Impacts of Applied Microbiology held in Helsinki, Finland, and gave papers at a United Nations Symposium there and at an international workshop in Costa Rica. Penny R. Hirsch attended the Second International Symposium on the Molecular Genetics of Bacteria–Plant Interaction at Ithaca, NY. K. E. Giller and J. F. Witty participated in the 6th International Symposium on Nitrogen Fixation held in Corvallis, Oregon in August and J. F. Witty and P. B. Tinker contributed to a workshop at Michigan, USA.

O. H. Ahmed of Medani, Sudan, who had a Technical Cooperation Training Award in the field of biological nitrogen fixation, completed three months with J. Jebb (AGC). Lief Skøt of Riso National Laboratory, Denmark, completed his two-year research period here in September and C. Wang from Anhui Academy of Agricultural Science, China, who was working on projects concerned with genetic studies of *Rhizobium* and vesicular-arbuscular mycorrhizal fungi, returned home in July. We welcomed B. Faber of the University of California, Davis for six months to work on the mycorrhizal programme, Concepción Azcon-Aguilar from Spain for six months and E. Koreish from the College of Agriculture, Alexandria, Egypt for three months.

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SOILS AND PLANT NUTRITION DEPARTMENT

Causes of yield variation

Comparison between previous crops. Earlier work has shown that previous cropping is a major cause of yield variation in winter wheat through its effect on soil-borne pathogens and residual nitrogen in soil. Work has continued on these effects.

Wheat following beans or wheat at Saxmundham. A bread-making wheat (Moulin) and a feeding wheat (Galahad) were each grown with a range of N dressings after winter beans and after winter wheat. On 28 November amounts of NO_3-N in the soil (kg ha^{-1} to 90 cm depth) were 73 and 26 after beans and wheat respectively. Yields were larger after beans than after wheat (7·38 *vs* 5·94 t ha^{-1}) and larger for the feeding than for the bread-making cultivar (7·52 *vs* 5·80 t ha^{-1}). The main dressing of N was applied on 16 April, maximum yields were given by 160 kg N ha^{-1} after beans and 220 kg N ha^{-1} after wheat. A fungicide and insecticide programme increased yields by at least 1 t ha^{-1} irrespective of variety or previous cropping. N applied on 5 March always caused severe lodging. Maximum yield (10·30 t ha^{-1}) was obtained from Galahad following beans and given 160 kg N ha^{-1} in April and the three-spray programme. (Widdowson, Penny, Darby, Bird and Hewitt)

Wheat following oats or rape at Rothamsted. The effects of soil and fertilizer N on tillering, growth and yield of wheat, cv. Avalon, sown in September 1984, were measured (see p. 34). Five factors at two levels were tested in all combinations: (1) previous crop, (spring oilseed rape *vs* winter oats) (2) winter N, 0 *vs* 60 kg N ha^{-1}, (3) early spring N, (single or split dressing); (4) late spring N, (single or split dressing); (5) summer N, (0 *vs* 60 kg N ha^{-1}). The amount of urea in (2) was based on soil NO_3-N levels. The remaining N was applied as 'Nitro-Chalk', the total of (3)+(4) was 180 kg N ha^{-1} after rape and 240 kg after oats, calculated to be enough for 12 t ha^{-1} grain.

Previous crop had the largest effect on yield via the soil nitrogen status. The large N supply during autumn and winter, either from soil residues following rape or from winter-applied fertilizer N, caused lodging in summer. Grain yields were well related to lodging, so that the best yield (10·66 t ha^{-1}) occurred after oats without winter N, and the lowest (9·82 t ha^{-1}) after rape with winter N. Applying the spring N early had little effect on yield, but for late spring N there was a small advantage from the split dressing (10·47 t ha^{-1}) compared to the single (10·15 t ha^{-1}). Summer N increased mean yield by 0·34 t ha^{-1}. Best yield from a combination of three factors (previous crop oats, late spring N divided, with summer N) was 10·88 t ha^{-1}. (Penny and Darby with Thorne and Wood, Physiology and Environmental Physics; Prew, Field Experiments and Todd, Statistics)

Factors affecting the yield of oilseed rape. A multifactorial experiment on oilseed rape, cv. Bienvenu, following winter barley was sited on a deep flinty loam (Charity complex). Seven factors each at two levels were tested (see Multidisciplinary Agronomy section) in combination using a half replicate design of 64 plots with 32 extra plots testing additional factors. Growth, nitrogen uptake, the incidence of pests and diseases, and yield were measured.

High winds and much rain between crop desiccation and harvest decreased yield by about 25% judged by measurements from hand-harvested samples made 18 days before combine harvest. The mean combine-harvested yield of all the factorial plots was 3·95 t ha^{-1}. Of the factors tested in factorial combination, only sowing date had a significant effect on yield, with the later sowing outyielding the earlier (4·28 *vs* 3·63 t ha^{-1}). Yields of the later sown crop were increased by applying 275 rather than 175 kg N ha^{-1} in two doses and a growth regulator at flowering; these treatments decreased yield of the early-sown crop, significantly so when growth regulator was applied. It is difficult to draw firm conclusions from these

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results which are from the first year of a series of experiments. Certainly larger yields with later sowing was unexpected and highlights the need for further work. (Darby; Bird and Hewitt)

The effects of drought and N-supply on the growth of winter wheat. Experiments on winter wheat testing the effects of drought on different soil types, and its interaction with N supply in Batcombe series soil (*Rothamsted Report for 1984,* 117) were extended in 1985 when a crop of cv. Avalon was grown under the new 8·5 m-wide demountable mobile crop shelter. Irrigation versus total drought and no N versus 160 kg N ha^{-1} were tested factorially on a soil that was fallowed in 1984 and carried wheat in 1983. The crop given both water and N gave a final shoot weight of 17·7 t ha^{-1}, drought reduced this by 13% and no N, with or without drought, by 54%. Maximum grain yield (8·3 t ha^{-1} DM) was reduced correspondingly, by 19% by drought alone and by 56 and 61% by no N, with or without drought respectively. The stressed crops had both fewer ears and grains m^{-2}. The roots of all crops grew to about the same maximum depth of 1·6 m, in agreement with earlier results showing that drought does not induce deeper rooting. However, the crop receiving both water and N had the largest root system, with 37 km m^{-2} of total root length weighing 139 g m^{-2} dry weight at anthesis. The root lengths of the other crops were reduced by 15, 26 and 32% respectively, i.e. usually by less than shoot or grain weight.

By anthesis there was no effect of irrigation on the N content (165 kg ha^{-1}) of crops given N. Subsequently the irrigated crop gained 15 kg N ha^{-1} but the droughted crop lost 21 kg ha^{-1}. Irrigation had no effect on N uptake (62 kg ha^{-1}) by crops given no N. The crop receiving both N and water used a total of 290 mm of irrigation plus stored soil water after covering on 17 April. The irrigated crop without N used 17% less while the droughted crops with and without N used 35 and 63% less, respectively. The droughted crop drew water from the total rooting depth of 1·6 m; that receiving N transpired at the same rate as the irrigated crop until 100 mm of soil water had been removed and then at a reduced rate until a total of 165 mm had been extracted. The droughted crop without N extracted 117 mm over the same total period with less water coming from each soil depth.

This crop of Avalon responded to a shortage of N or water by reducing shoot growth with corresponding, but smaller, reduction in root growth. Most of the difference in root growth occurred in the top 20 cm of soil. The droughted crop supplied with N removed a total of 165 mm of water from Batcombe series soil compared with 290 mm used by the irrigated crop, but suffered a yield penalty of only 19%; drought had a much smaller percentage effect on yield when a severe shortage of N was the main limitation to growth. This work is being extended to measure uptake of nitrate leached into the deeper subsoil. (Weir, Barraclough and Kuhlmann; Smith, Doran, Ashton, Green and Kent)

Efficient use of applied fertilizer nitrogen

Effects of previous cropping on the recovery of fertilizer N by winter wheat. Spring-applied N can be lost from the crop-soil system by leaching of nitrate or by denitrification to oxides of nitrogen or nitrogen gas which are then lost to the atmosphere. Both represent a financial loss to the farmer and, in addition, nitrates leached into potable waters may pose a health risk. It is difficult to measure leaching losses directly except in experiments with under-drainage; this will be done at Brimstone (p. 176). Indirect measurements have been made on other soils using chloride as a marker for nitrate (*Rothamsted Report for 1984,* 180) or have been predicted by modelling. Denitrification losses were measured directly by the acetylene blocking technique in 1985 in an experiment which measured recovery of spring-applied ^{15}N-labelled fertilizer given to winter wheat. The wheat was grown on similar soils of contrasted cropping history; for nearly 40 years one had been in continuous arable crops ('Arable')

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whilst the other ('Ley') had been in a six-year cycle of three years grass-clover ley followed by three years arable crops. The wheat crop followed either the ley or sugar beet and then oats so that both crops were likely to be free of soil-borne foot rot diseases. The plots were irrigated to field capacity before ^{15}N-labelled fertilizer (222 kg N ha^{-1} as $K^{15}NO_3$) was applied on 23 April; this gave the greatest opportunity for denitrification to occur. The crop was harvested at anthesis to measure maximum N uptake.

On the 'Arable' soil virtually all of the ^{15}N-labelled fertilizer was recovered at anthesis with 173 kg in the crop and 44 kg in soil to a depth of 70 cm. On the 'Ley' soil, less fertilizer N was recovered in the crop (122 kg) and more in the soil (73 kg) as expected, and total recovery on the 'Ley' (88%) was a little less than on the 'Arable' soil (98%). Thus losses of N applied in April were small in 1985. Direct gas-phase measurements showed that denitrification losses were indeed small. However, in contrast with the recoveries measured by ^{15}N, denitrification losses were a little greater on the 'Arable' treatments than on the 'Ley'; the total amount lost was 11·8 and 8·5 kg ha^{-1} respectively. The small losses were presumably the result of the cold dry weather which immediately followed the application of fertilizer. Of the total N lost by denitrification a large proportion went about three weeks after the N was added. At that time heavy rain during warmer weather was followed by an immediate flush of mineralization; denitrification rates then reached >1·0 kg N ha^{-1} day^{-1} over several days. Denitrification occurred when soil NO_3-N concentrations were $>5\,\mu g\,g^{-1}$, soil moisture content was >20%, and soil temperature was >8°C. Further work will be done to evaluate critically different methods of measuring denitrification under field conditions. (Powlson, Goulding, Poulton, Jenkinson and C. P. Webster; Hellon, Brown and McCann)

Recovery of early dressings of fertilizer N by oilseed rape. Oilseed rape receives large dressings of N in early spring so that there is a serious risk of nitrate being lost by leaching. To measure this loss 254 kg N ha^{-1} was applied as $^{15}NH_4{}^{15}NO_3$ on 4 March to a crop sown on 16 August 1984 and given 50 kg N in the seedbed. At final harvest 63% of the fertilizer N was recovered in the above ground parts of the crop, 16% in soil (0–23 cm depth) and 3% in leaf litter on the soil surface. Thus, 82% of the labelled fertilizer N was accounted for, with probably a little more in soil below 23 cm. This small loss, about the same as measured under winter wheat given N in April, was almost certainly a result of low rainfall (70% of average) and low soil temperatures in the few weeks following fertilizer application. Soil temperatures were too low for denitrification to be important.

An unexpected result was the large uptake of unlabelled N derived from soil. Plants given no N in spring, contained 168 kg N ha^{-1} at harvest. Because of the large supply of N from soil and seedbed fertilizer, the 254 kg N ha^{-1} spring dressing was well above the crop's requirements and caused only a small increase in seed yield (4·46 to 4·64 t ha^{-1} at 90% DM).

Of the 254 kg N ha^{-1} applied as fertilizer in spring 85 kg ha^{-1} was in pods, straw, stubble and leaf litter and 42 kg ha^{-1} in organic and inorganic forms in soil after harvest. The size of this residue is considerably larger than that following a cereal and its value to a succeeding crop of winter wheat will be measured. (Powlson, Poulton, Rodgers and Jenkinson; Brown and McCann)

Effect of prilled urea, used alone or with a urease inhibitor, and of 'Nitro-Chalk' on winter oilseed rape. Because of the time lag between addition of urea and its hydrolysis and subsequent nitrification it could be suitable for early N applications to oilseed rape. Prilled urea, with or without a urease inhibitor (hydroquinone), was compared with 'Nitro-Chalk' in 1984 and 1985. Each fertilizer was applied at 50 kg N ha^{-1} to the seed bed, followed by 150 kg N ha^{-1} broadcast in early spring either as a single dressing or two equal dressings.

Seed-bed nitrogen increased plant growth during autumn and winter in both years but increased yields only in 1985. Scorching of plant leaves was severe in spring after application

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of urea as a single dressing, but was much less with urea plus hydroquinone or when the dressing was divided. Ammonia volatilization losses from urea were reduced by hydroquinone, though they were always less than 3% of the nitrogen applied. Soil pH rose rapidly after urea application and thereafter fell slowly, whereas pH fell immediately after application of 'Nitro-Chalk'. Overall, seed yields with urea were 90%, and with urea plus hydroquinone 97%, of those with 'Nitro-Chalk'; dividing the spring dressings increased yields in 1985 but not in 1984. Yields from divided and single dressings of 'Nitro-Chalk' were similar in both years. (Rodgers and Penny; Hewitt)

Nitrogen prediction system

Nitrate leaching. Our earlier leaching model (Addiscott, *Journal of Soil Science* (1977) **28,** 554–563) contained assumptions that implied that soil drained to 'field capacity' very rapidly but this is not so in many clay soils. This model has been improved. In the new version rainfall infiltrates into the soil and a proportion of the water surplus to field capacity is redistributed downwards. Water movement is accompanied by solute movement. This model gave a good simulation of nitrate leaching on a silty clay loam and a much better simulation than the previous model of the chloride leaching measured by Cameron and Wild (*Journal of Soil Science* (1982) **33,** 659–669) in a thin Andover series soil overlying chalk. (Addiscott and Whitmore; Heys with Barriball, Sandwich Student)

N requirement prediction. One new development of the system for predicting the nitrogen requirements of winter wheat crops (*Rothamsted Report for 1984,* 181–182), is the adaption of the system to predict the nitrogen requirement of sugar beet (p. 44). Another, being developed for use by winter wheat growers, is to use the model to compare the amounts of mineral N in soil and N in crop during autumn, winter and early spring with long-term means from previous years. In spring the system can also be used to predict leaching of applied fertilizer N. These two types of prediction have to be based on current weather data and given on the basis of climatic area, soil type and previous cropping. They can be updated weekly from January to April. Predictions are being made for parts of Eastern England and will be available on two commercial viewdata systems. This is being supported by a MAFF Open Contract appointment. (Whitmore and Addiscott; Heys)

Computer assessment of seasonal differences and management practices on nitrogen leaching losses under winter wheat crops. The N prediction system has been used mainly to simulate the amounts of nitrogen in the soil and crop. It also simulates leaching losses, and the satisfactory simulations of soil and crop nitrogen (*Rothamsted Report for 1984,* 182) suggest that estimated leaching losses cannot be far wrong unless denitrification occurs. For two of the sites at which the system has been fully validated the relative effects of seasonal differences and management practices on nitrate losses have been assessed. This used actual weather data from 14 winters (1970/1–1983/4) and different conditions, e.g. site, date of sowing, residual mineral N in the profile in autumn, applied fertilizer N in autumn, and presence of field drains, in a 14×2^5 factorial design. Of these factors residual N normally had the largest effect. Seasonal effects were also substantial, with the mean losses in the wettest and driest years being 100 and 10 kg N ha^{-1} respectively. Site and early sowing accounted for an appreciable proportion of the variation in the quantity of N lost. On average, half of any N applied in autumn was lost, and what was left had little effect on the amount of N in the crop in spring. The concentrations of nitrate in drainage also varied greatly between years, even for pairs of years in which the total rainfall differed little, showing the importance of differences in the distribution of rainfall during the winter. These results suggest that it may

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be possible to predict nitrate leaching into groundwater on a field basis. This could be a useful tool for overall monitoring of nitrate pollution, and arrangements are being made to validate this. (Whitmore and Addiscott; Heys)

Soil organic matter and biomass

Effect of heavy metals on soil microbial biomass. An experiment started in 1942 on sandy loam soil at Woburn has compared the effects of various organic manures with those of inorganic fertilizer on several arable and horticultural crops. The metal content of the soils was increased to levels above those which would now be permitted by current guidelines where 25 dressings of sewage sludge and sludge-straw compost, both at two rates, were applied between 1942 and 1961. The proportion of EDTA-extractable to total soil metal has not changed with time (*Rothamsted Report for 1984,* 185). There were few effects of heavy metals on above-ground yields of crops grown on this experiment, probably because soil pH was maintained above 6·5. However current guidelines do not consider possible effects of metals on soil microbial processes because these have not been studied.

By the 1980s the soils contained EDTA-soluble metal concentrations ranging from a half to one and a half times those permitted under current guidelines and the soils were considered to have reached equilibrium. The main conclusions so far are that microbial biomass, soil N_2 fixation by blue-green algae and clover yields in pot experiments are all less in soils that received metal-contaminated sewage sludge compared to those that received farmyard manure. The high-metal soils contained more total organic matter than low-metal soils but, unexpectedly, contained smaller biomasses. The blue-green algae, one component of the soil biomass, grew very poorly, and fixed little N_2, on the high-metal soils. Yields of tops and roots of clover in pot experiments were very much reduced in the high-metal soils and the shoot/root ratio was also higher. Visual observation of the clover roots showed that those grown in high-metal soils had many more, but very much smaller, mainly white, nodules than those in low-metal soils. This proliferation of small nodules suggests that they were not fixing nitrogen (Fred, Baldwin & McCoy (1932) *Root nodule bacteria and leguminous plants*) hence yields of tops and roots were small. Thus, as with the blue-green algae, the metals appear to depress nitrogen fixation. We are as yet unable to totally explain the effects of these metals which may act directly on the biomass or indirectly via the amount of plant material returned to the soil. The problem is being vigorously investigated. (Brookes, McGrath; Giller and Heijnen)

Root studies

Organic matter and the diffusion of ions in soil. Most nutrients must diffuse to roots before uptake, but diffusion of ions in soil is affected by the tortuosity of the pathways they follow. Ionic impedance factors, which are a measure of this tortuosity, depend greatly on soil texture, water content and bulk density. Recent measurements on diffusion used bromide because it behaves like nitrate, but does not undergo biological transformation in soil. The results confirm that organic matter affects impedance factors in a similar way to clay content. Two silty clay loam soils which had similar particle size distributions, but a four-fold difference in organic-C content (3·2% and 0·8%) were used. At a given volumetric water content, the impedance factor of the high-C soil was up to 50% greater than that of the low-C soil so that diffusion is easier in the high-C soil. Similar results were found with two lighter textured soils. (Barraclough; Cooper)

Nutrient uptake activity of nodal and seminal roots of winter wheat. When modelling nutrient uptake it is important to know if there are intrinsic differences in the functioning of

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different members of the root system. The activity of seminal and nodal roots of winter wheat, cv. Avalon, in taking up NO_3^- and K^+ was measured by depletion from nutrient solutions using a split-root technique.

Inflows (uptake rate per unit root length) were up to six times higher for nodal roots than seminal roots, but there were no significant differences in specific absorption rates (uptake rate per unit root fresh weight). Values in the range 1–2·3 pmol mg^{-1} s^{-1} were found for N and 0·4–1·0 pmol mg^{-1} s^{-1} for K. Uptake rate per unit of root decreased with plant age as a result of a declining relative growth rate of the shoots. When either the nodal or seminal root system alone was supplied with nutrients for one week, uptake rate per unit of that root increased and both nutrient uptake and plant growth were maintained at the same level as when both root systems received nutrients. This illustrates the great flexibility of the cereal root system, but the mechanism whereby it happens is not understood. (Kuhlmann and Barraclough)

Use of root observation tubes in field studies. Quantitative measurements of root growth using perspex observation tubes (minirhizotrons) and by soil coring, have been made for September-sown wheat. The tubes were useful for measuring rooting depth although tube to tube variability was large. On 13 December, for example, there was a mean rooting depth of 72 cm (coefficient of variation 25%, range 31–107 cm) and a 15-fold range in the total rooting densities observed at individual tubes. Maximum rooting density occurred at 40–50 cm depth, and was never observed in the 0–20 cm layer. Such distributions are very different from those previously obtained by coring. We have no explanation for this at present, but other workers have had similar results. At anthesis, the number of roots observed down the whole profile was 60% greater on plots given 180 kg N than on those given no N. This effect of nutrients on total amounts of roots was similar to that (40%) obtained from coring. These results indicate that results with observation tubes must always be confirmed by coring, especially for root distribution. (Barraclough; Doran, Kent, Ashton and Green)

Plant composition and nutrient uptake

X-ray microanalysis of cells and cell compartments in potassium deficient barley leaves. X-ray microanalysis has been used to determine the distribution of cations between cells and cell compartments in leaves of barley plants grown with adequate and inadequate potassium supplies. With sufficient potassium, this was the most abundant cation in all cells and cell compartments. When its supply was insufficient, potassium was not detected in vacuoles of mesophyll cells, which accumulated sodium and magnesium instead. In contrast, the cytoplasm of these cells still contained detectable potassium and increases in sodium and magnesium were less marked, supporting a recently proposed model describing the distribution of potassium between vacuole and cytoplasm (Leigh & Wyn Jones, *New Phytologist* (1984) **97,** 1–13). The behaviour of chloroplasts was similar to that of the cytoplasm. The potassium deficient leaves contained increased calcium concentrations, but none was detected in the mesophyll cells, all detectable intracellular calcium being in the vacuoles of epidermal cells. This indicates that differences in the intercellular distribution of solutes will have to be considered to understand the response of plants to nutrient deficiency. (Leigh with Dr R. Storey, CSIRO Division of Horticultural Research, Merbein, Victoria, Australia).

A proton pumping inorganic pyrophosphatase associated with the tonoplast of oat roots. Beet vacuoles possess a membrane-bound inorganic pyrophosphatase and this activity functions as a proton pump (Walker & Leigh, *Planta* (1981) **153,** 150–155). A similar activity has now been found in tonoplast from oat roots. Inorganic pyrophosphate induced a

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pH gradient (inside acid) and a membrane potential (inside positive) in oat root tonoplast vesicles indicating an inwardly-directed, electrogenic, pyrophosphate-dependent proton pump. Proton pumping was potassium dependent (K_m=4 mM) and maximum rates of proton pumping were obtained with about 60 μM pyrophosphate. Under optimal conditions the rate of pyrophosphate-dependent proton transport was as great as that by the proton-translocating ATPase that is also associated with tonoplast.

Unlike the ATPase, the pyrophosphatase was not affected by nitrate and chloride, nonetheless these anions increased pyrophosphate-dependent proton transport. Chloride consistently stimulated pH gradient formation, probably because it relieved the membrane potential. In some preparations nitrate acted in a similar way but in others it inhibited pH gradient formation. The latter behaviour is taken as evidence for the presence of a proton-nitrate symport for unloading nitrate from the vacuole (Blumwald & Poole, *Proceedings of the National Academy of Science* (1985) **82,** 3683–3687). Why this is only present in some preparations of tonoplast is unclear. Nonetheless this is a promising system for studying the transport of anions into and out of the vacuole. (Leigh and Pope with Dr H. Sze, Dr Y. Wang and Mr K. H. Kaestner, University of Maryland, USA)

Grain quality

Wheat grain quality. Sieve size fractions, specific weights in kilograms per hectolitre (kg hl^{-1}) and weights of 1000 dry grains were determined on samples of grain from Broadbalk (cv. Brimstone), a straw-incorporation experiment at Rothamsted (cv. Avalon), a multifactorial experiment at Saxmundham with two cultivars (Galahad and Moulin), and finally, one at Rothamsted testing factors affecting tillering and yield (cv. Avalon). The size fractions determined were <1·0, 1·0–2·0, 2·0–3·5 and >3·5 mm. The amounts of trash (<1·0 mm) and very large grain (>3·5 mm) were very small. The 1–2 mm fraction was also small, usually less than 2%, probably because there was no water shortage during grain filling. Specific weights were determined on the 1·0–3·5 mm fraction at 85–87% dry matter. This fraction was used because most on-farm grain cleaners will remove material less than 1 mm. The weights of 1000 grains were also determined on the 1–3·5 mm fraction.

On Broadbalk yields ranged from 1·4 to 9·8 t ha^{-1} and specific weights from 63·2 to 75·2 kg hl^{-1}, but yield and specific weight were not related. Increasing the amount of spring-applied N from 48 to 288 kg ha^{-1} had no consistent effect on specific weight (69·2–73·2 kg hl^{-1}). Omitting pesticides decreased yields and also specific weights by 1·8 kg hl^{-1} (71·9–70·1). The largest effect on specific weights was on plots not given K for 150 years, giving K increased specific weight from 67·2 to 71·0 kg hl^{-1}.

Shallow incorporation of straw and stubble or stubble alone compared with burning had little effect on yields (pp. 33, 173) or specific weights. Aphicide also little affected specific weight but fungicide, to control leaf diseases, increased yield and also specific weight (72·9–76·2). In the third experiment there were significant differences in specific weights (kg hl^{-1}) after beans (76·1) compared with after wheat (74·5) and of Moulin (76·6) compared with Galahad (74·0). N fertilizer had little effect on grain size, specific weight or 1000 grain weights, except that omitting N decreased specific weight. Control of aphids and diseases had no effect on the proportion of 2·0–3·5 mm grain after beans but slightly increased it after wheat; specific weight of Galahad, but not of Moulin, was increased slightly more after wheat than after beans. In the fourth experiment, preceding crop (oats or rape) winter N, single and divided early and late spring N and summer N were all tested. Rate and timing of N had no effect on specific weight which was only affected by preceding crop, oats 77·5, rape 76·8 kg hl^{-1}. In all experiments the most consistent effect was that of fungicides, with differences also due to cultivar and preceding crop. The effect of potassium deficiency is interesting, but unlikely to be important in farm practice except on the lightest soils. (Penny and Hewitt).

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Micronutrients in soils and crops

Persistence of metals in soils due to past sewage sludge applications. A metal balance for sludge-treated plots in a long-term experiment (*Rothamsted Report for 1984,* 185) is being compiled. Of the metals added in sewage sludge during 1942–61, 80% and 40% were detected in soil from the plough layer (0–27 cm) in 1960 and 1980 respectively. Estimates of the total amounts of metals removed in the crops harvested between 1960 and 1980 were less than 0·5% of the amounts added during 1942–61. Analysis of soil profile samples taken in 1960 and 1982 showed no detectable increase in subsoil metal concentrations. This result is supported by the fact that metal solubilities in the soil solution were extremely low so that losses in drainage water were small.

However, modelling of the soil metal concentrations in transect samples taken across plots with and without sewage sludge (*Rothamsted Report for 1984,* 77) showed that significant quantities of soil have been moved between plots, but within the plough layer, as a result of cultivation. Soil moved from sludge-treated plots has taken with it the metals it contained, so that apparent lower recoveries of metals in 1980 compared to 1960 are most probably the result of soil movement. It is likely that most of the heavy metal load added to soil from the sludge will be accounted for in the plough layer when 'losses' due to soil movement have been taken into account. (McGrath; Hellon and Brunsdon, with Lane, Statistics)

Plant uptake of metals added to soils in sewage sludges. Three glasshouse experiments measuring effects of soil factors on availability to plants of metals added to soils in sewage sludges have been concluded. The first experiment tested high concentrations of zinc, copper and nickel added to four soils of contrasting pH and texture; the EDTA-extractable metal concentrations were near or above the maximum allowed in current guidelines. Chemical studies on these mixtures have been reported (*Rothamsted Report for 1982,* Part 1, 268; *1983,* 178; *1984,* 185). The soils were cropped continuously with clover or with red beet and barley in rotation for 21 months. Metal concentrations were higher in crops grown on light as opposed to heavy textured soils and (except for copper) on soils of pH <7. Barley showed no metal-induced yield reductions, but yields of red beet and clover grown on a sandy loam (whose pH decreased from 7·0 to below 6·0 during the experiment) were depressed by high zinc and nickel concentrations.

In the second experiment the same sludges were added to samples of a silty clay loam, (Batcombe series) and a sandy loam (Stackyard series) on which pH levels between 4 and 7·5 had been established in the field; these soils were cropped with ryegrass for six months. Zinc and nickel concentrations in ryegrass changed with soil pH over the whole range, but copper concentrations were steady above pH 5·5. Yield was decreased by all metals when the pH was 5·5 or below.

In the third experiment soils from three Danish field trials were cropped with barley and red beet in rotation. The concentrations of zinc, nickel, cadmium and copper in plants grown on sludge-treated soils were higher than those grown on unsludged soils and were influenced by soil pH and texture, but there were no metal-induced yield reductions.

In all three experiments plant metal concentrations were well related to metals extracted by 0·1 M $CaCl_2$, buffered EDTA or DPTA, and to metal concentrations in displaced soil solutions.

Current recommendations state EDTA-extractable metal concentrations in soils should not exceed 280, 140 and 35 mg kg^{-1} Zn, Cu and Ni or a zinc equivalent of 280 mg kg^{-1} and that the soil pH should be maintained above 6·0 (grassland) or 6·5 (arable crops). Our results suggest that these are generally satisfactory, as far as the phytotoxic and possible human or animal health effects of these three elements are concerned. (Sanders, Adams and McGrath, with Dr B. T. Christensen, Askov Experimental Station, Denmark; Brunsdon and Freeman)

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Micronutrient concentrations in wheat grain. Concentrations of P, K, S, Ca and Mg varied twofold, Fe, Zn and Cu threefold, whilst Mn varied by a factor of five in winter wheat grain from a UK sampling survey by the Home-Grown Cereals Authority in 1982. Small varietal differences in grain composition were detected. On average, 6 t ha^{-1} of grain removed (in kg ha^{-1}) 22, P; 29, K; 10, S; 2·6, Ca; 6·4, Mg; 0·2, Na; 0·2, Fe; 0·2, Zn; 0·03, Cu and 0·2, Mn.

Composition of grain from Rothamsted experiments on three farms with yields larger than 10 t ha^{-1} was determined also; percentage Fe, Zn, Cu and S, but not Mn, increased as yield increased. Foliar fungicidal sprays containing Mn gave increased grain Mn concentrations in 1981 and 1982, but S-containing sprays did not alter grain S when applied in 1983. These results suggest that as yields increase probably only the Mn content may be a cause for concern; Mn deficiency is the most common trace element deficiency observed in UK cereals and this probably warrants some work on Mn uptake during growth and effects on yield. (McGrath; Hellon)

Phosphate fertilizers

The importance of water-soluble phosphate in phosphate fertilizers. A three-year programme funded by Norsk Hydro Fertilizers Ltd assesses the importance of 'water solubility' in phosphate fertilizers because this is still the main criterion by which such fertilizers are judged.

Laboratory-made fertilizers ranging from 0 to 100% water-soluble phosphate (the non-water soluble component being dicalcium phosphate) and single superphosphate were compared using ryegrass in pot experiments in the glasshouse at Rothamsted and Levington. The soils used ranged in texture from clay loam to sand, in soil pH from 5·1 to 7·5 and in P status from 10 to 52 mg P l^{-1}. On the acid soil used at Rothamsted yields did not decline appreciably until P water-solubility fell below 20%, but on the neutral soil yields began to decrease when it fell below 80%. On the acid soils used at Levington yields declined when the fertilizer had less than 60% water-soluble P irrespective of soil P status. On soils with pH greater than 6·5 yields declined slowly as water solubility decreased to 60% and then more rapidly below this.

In a field experiment on a low P soil (ADAS P Index 1) spring barley (Klaxon) tested three rates—20, 40 and 60 kg P_2O_5 ha^{-1} of nitrophosphate fertilizers with 59%, 73% and 95% water-soluble P. Barley yields ranged from 7 to 8 t ha^{-1} but showed no response to application rate or P source other than an overall response over the nil plot. (Copestake and Johnston with Dr G. A. Paulson and Dr I. R. Richards, Norsk Hydro Fertilizers Ltd.)

Straw incorporation

Many farmers are concerned about alternative methods for straw disposal if a ban on, or much tighter controls of, straw burning were to be introduced. The AFRC Straw Operations Group was set up to coordinate work on straw disposal techniques at four Institutes, Rothamsted, Long Ashton, National Institute of Agricultural Engineering and Glasshouse Crops Research Institute, and liaise with ADAS. Rothamsted took over responsibility for the Letcombe experiment started in 1980 at Northfield, near Faringdon and subsequently ancillary experiments have been started there; results are reported here. Two new experiments at Rothamsted and one at Woburn were started in 1985 (p. 32) and another was started in autumn 1985 at Waddon, near Bletchley, on the farm of one of the Friends of Rothamsted.

Methods of alleviating the adverse effects of straw. The long-term Northfield experiment, started in 1980 on a clay soil (Lawford series), compares straw burning with leaving the

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stubble or stubble plus chopped and spread straw. The crop was either direct drilled or sown after a shallow cultivation; all treatments are cumulative.

Where the crop was direct drilled, yields were 17% less in 1984 in the presence of straw compared with those following burning. Yields with shallow tillage (5–7 cm) following burning remained fairly consistent during 1980–84, average 9·2 t ha^{-1}, but those following similar tillage to incorporate chopped straw each year declined steadily and by 1984 they were only 4·6 t ha^{-1}. Autumn N benefited yields on direct drilled plots of the stubble treatment in 1983 and 1984 and on burnt plots in 1984, and increased yields on shallow cultivated plots by, on average, 0·6 t ha^{-1} with burning and by 0·4 t ha^{-1} with chopped straw.

Results from the first phase clearly indicated that there was a serious yield penalty when straw was shallowly incorporated. So in autumn 1984 the depth of burial of straw residues was tested with direct drilling and three depths of cultivation (5, 15, 25 cm). A plough was used for cultivation because tines were not efficient at 25 cm at one pass on this heavy soil. Following ploughing seedbeds were poor. Winter wheat, cv. Avalon, a fourth wheat, yielded best (6·3 t ha^{-1}) following burning straw and direct drilling; the incorporation of ash to 5, 15 and 25 cm decreased yield to 5·8, 5·6 and 5·3 t ha^{-1} respectively. Incorporating stubble to 5, 15 and 25 cm gave yields of 6·1, 5·7 and 5·4 t ha^{-1} respectively, all significantly larger than the yield (4·0 t ha^{-1}) following direct drilling into stubble. Lowest yield followed direct drilling into chopped straw (2·9 t ha^{-1}) but where straw was incorporated to 5, 15 and 25 cm yields were better, 5·5, 5·6 and 4·7 t ha^{-1} respectively. With all straw disposal treatments yields were closely similar at the 15 cm depth of cultivation and no differences in yield between straw disposal methods at any one depth of incorporation were statistically significant. Poorer yields with 25 cm incorporation may have been due to ploughing up unweathered subsoil. All the plots where straw was ploughed in were affected by volunteer cereals, and these may have influenced final yield. Leaf stripe (*Cephalosporium gramineum*) was measured in June 1985 for the third successive year and was again more severe where straw was present. Effects of deeper incorporation on pests and diseases will be monitored over the next few years. (Christian and Bacon)

Toxin production and oxygen demand. Crop residues left on the soil surface or only shallowly incorporated may give phytotoxic compounds if they decompose anaerobically. The potential to produce anaerobic toxins is lost progressively during decay; hence the recommendation that drilling should be delayed for four to six weeks after straw incorporation.

In controlled environments the size of wheat seedlings grown in soil-straw mixtures was decreased most when seed was sown four to six weeks after mixing straw with soil. At a soil temperature of 10°C, typical of early autumn, the uniform incorporation of straw, at 20 t ha^{-1} equivalent, into a 10 cm layer of soil did not cause oxygen demand to exceed supply even when only pores larger than 150 μm were air filled. However shoot/root ratios for winter wheat cv. Avalon were reduced by about 10% by straw. These effects were independent of those due to immobilization of soil nitrogen during straw breakdown. (Goss, Harper and Smallfield)

Transport processes in soils

Groundwater movement and land drainage. The performance of a drainage installation is well described by the recession curve of the drain hydrograph. A graphical method, derived from a power-law drainage equation, allows drainage characteristics to be obtained simply from these hydrographs. The method has been used to characterize drain performances in terms of two parameters, one that depends on the spacing of the drains and their height above an impermeable floor, and the other that depends on the hydraulic conductivity and

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specific yield of the soil. It has been used in our investigation of the effect of cultivation and of the seasonal change in the performance of mole drains. Cultivation delayed drainage, seasonal swelling and shrinking of the soil changed the drain performance in a complex manner. (Youngs; Shipway with Dr P. Leeds-Harrison, Silsoe College)

Water movement in soils. New techniques in image analysis and other methods of studying soil morphology enable the geometry of the macropores to be described quantitatively. Potentially these developments allow us to calculate flows of water and other liquids through the soil. Several workers have applied the standard textbook formulae for laminar flow in cylindrical tubes and between parallel planes of infinite extent to model water flow in macropores. However, macropores consist more usually of channels of various and often irregular shapes, so that it becomes desirable to apply formulae that are more appropriate to the true shapes. The standard formulae have been extended and Stokes-Navier equations solved by numerical analysis to include flow in elliptical tubes, between planes of finite width but infinite length, and between planes of finite width and length. More computing power is needed to combine these results for complex networks. (Towner)

Drainage and cultivation: the Brimstone Experiment. In 1978 a field experiment was begun by the AFRC Letcombe Laboratory and the MAFF Field Drainage Experimental Unit on a 10 ha site at Brimstone Farm near Faringdon, Oxfordshire (Cannell *et al., Journal of Agricultural Science, Cambridge* (1984) **102,** 539–559). The current experimental treatments are; (a) without and with a mole and pipe drain system; (b) ploughed conventionally versus direct drilled. Each plot was separated from its neighbours by polythene barriers to 1·1 m and interceptor drains. Surface water run-off and flow in soil and mole channels are measured. The volume of drainage water and its content of nitrate and nitrous oxide are determined.

Between 1978 and 1983 the discharge from the drains of drained plots was somewhat more than the total rainfall, suggesting lateral flow into these plots. In the summer of 1984 the depth of the barriers around four plots was increased by inserting additional polythene membranes and interceptor drains to 1·8 m. In 1984–85 cracks produced in the previous summer remained open throughout the dry winter, and the success of the remedial measures will not become apparent until these have sealed. The 1983–84 season rainfall of 505 mm, 73% of the 30-year average, resulted in only 73 mm of drain flow, the water table reached the A horizon only for a short period and only on the undrained plots. Yields of winter wheat cv. Rapier in 1984 were large and somewhat greater on drained land (11·7 t ha^{-1}) than on the undrained plots (11·3 t ha^{-1}). Both cultivation treatments yielded on average 11·5 t ha^{-1}.

Oilseed rape, cv. Bienvenu, was grown in the 1984–85 season and yielded, on average, 3·6 t ha^{-1} seed with an oil content of 49%, with no main effect of either drainage or cultivation. However, there was an interaction: on ploughed land, heavier yields were obtained on the drained plots than on the undrained ones. For autumn sown crops the interactions between drainage and cultivation have so far been small. Future work will measure movement of nitrate to the drains and subsequent losses both in drainage water, and by denitrification. Consideration will be given to growing spring sown crops where an interaction between cultivation and drainage status might be more important. (Goss, Christian, Howse, Bacon with Mr G. Harris of the Field Drainage Experimental Unit)

Soil structure and tillage

A new approach to understanding the basis of structure, strength and stability of soil is being undertaken. This involves a coordinated study of the interparticle forces in clays, and later in clay and larger particle mixtures, together with studies of the bulk physical properties of the

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soils. Three soils, with contrasting properties, are being used for this. They are the principal soils from our experimental farms, namely, Batcombe series from Rothamsted, Beccles series from Saxmundham and Stackyard series from Woburn, all well documented in previous annual reports.

Interparticle bonding. Soil aggregates are stable because of the attraction between the surfaces of individual soil particles. It has proved very difficult to measure these forces directly. The shear modulus of a system of interacting particles, however, is related to these forces and can be measured using a pulse shearometer. It is essentially a measure of the response of the system to very small deformations. The shear modulus has been measured for the $<2\mu m$ size fractions of three soils of contrasting mechanical behaviour from the Rothamsted farms. The samples were thixotropic, and the shear moduli increased with time to an asymptote, and the relationship can be well described by a double exponential model. This suggests that the links between the clay particles are of two kinds. The shear modulus of all the soils increased sharply as the solid concentration increased above 25% w/w, increased with ionic form in the order $Ca^{2+} \approx Mg^{2+} < K^{+} < Na^{+} < Li^{+}$ and varied in a complex manner with electrolyte concentration. The strength of the soil aggregates in the field and the shear modulus both varied in the same order for the three soils: Saxmundham (Beccles series)>Rothamsted (Batcombe series)>Woburn (Stackyard series). The method is now being extended to study the effects of iron oxides on structural stability. (Piper; Chandler and Sills)

Particle-size distribution and soil properties. A large sample of each of these three soils was separated into nine fractions with respect to particle size. The fractions were recombined in varying proportions, including those of the three original soils. They were formed into cylinders, the dry compressive strengths of which were measured. Aggregates with a given particle-size distribution from the different parent soils were similar, with those from the Batcombe distribution being the strongest. Bulk densities of saturated reconstituted soils were estimated from the densities and swelling properties of the separate fractions. These estimates agreed with the measured values. Breaking strengths of air-dry soils were estimated from the densities, strengths and swelling properties of the separate fractions. These agreed with measured values for the Batcombe distribution from all parent soils, but only for the Beccles distribution from the Beccles soil. Further investigation of the role of interparticle forces and cementing agents are needed to explain fully the field behaviour. (Towner and Pritchard)

Cracking. Most clays shrink on drying during which tensile or shear stresses are set up. Cracking occurs when the stresses exceed the tensile or shear strengths respectively, and this is the most important structure-forming process in the field.

To understand the process the mechanics of cracking are being studied in laboratory experiments. Remoulded clay bars of the same initial length, and constrained to prevent longitudinal shrinkage during drying, cracked at essentially the same water content irrespective of their initial water contents. From separate determinations of tensile strength and soil-water suction over a range of water contents, it was deduced that the tensile strength, and hence the induced tensile stress, at cracking was much less than the corresponding soil-water suction. Theoretically, the tensile stress is equal in magnitude to the soil-water suction when the shrinkage is isotropic. The freedom to shrink in two directions must therefore partly relieve the stresses in the constrained direction by a reorganization of the clay particles. Wet soil in the field will tend to shrink anisotropically downwards as it dries until the stresses can no longer be relieved, at which point it will crack. The resulting soil will be anisotopic. (Towner)

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Simplified tillage and controlled traffic. Two field experiments, begun by the Letcombe Laboratory in 1974, studied the long-term effects of simplified tillage and compared them with those of traditional mouldboard ploughing for winter wheat (see *Annual Report for Letcombe Laboratory 1981–82*). Both sites were on clay soils (Denchworth and Lawford series) and yields of wheat, cv. Huntsman, were 8% more after direct drilling than after ploughing. However, the heavier yielding cultivar Rapier was also grown in 1983–84 on the Denchworth soil and cultivation had no effect on its grain yield, 11·4 t ha^{-1}. Both have now finished. (Goss, Christian, Bacon and Howse)

In these experiments compaction of the soil under traffic was not wholly alleviated by using simplified cultivations. Three experiments tested the benefits of keeping all wheelings within well defined permanent tramlines. Two have been concluded. In the third, on Evesham series (clay) at Silsoe, Bedfordshire, soil conditions and distribution of roots were assessed in 1984 and 1985. The topsoil of both direct drilled and shallow tined land was more dense on plots receiving normal traffic than between the tramlines on controlled traffic plots. The denser soil also held more water because the proportion of fine pores was increased. Root development of winter wheat was little affected by these differences. More water was extracted by direct drilled crops than by those on tine cultivated soil, particularly below 0·5 m, but the efficiency of water use (weight of dry matter produced per mm water used) was similar on all treatments so it seems unlikely that drought was a factor. Grain yields were less on plots where there was controlled traffic, probably because these plots suffered from manganese deficiency which was not controlled soon enough. The advantage of controlled traffic systems over conventional tillage is that they require much less energy and do not compact the soil. In this particular experiment lack of compaction appeared to cause manganese deficiency, which could have been corrected cheaply by spraying. (Goss, Howse, Powell with Sarah Ayling, Long Ashton Research Station and Mr W. C. T. Chamen of the National Institute of Agricultural Engineering)

Cultivation and the physical properties of seedbeds. An unsuitable seedbed environment can limit yields, particularly for crops such as vegetables and sugar beet that do not compensate for poor establishment. Different ways of preparing seedbeds have been compared, using onions as a test crop, and the physical conditions of the seedbeds were measured from time of sowing to full emergence. Different water regimes were superimposed by sheltering subplots from rain. Where the soil had been cultivated in autumn and drilled directly in spring, emergence was better and quicker than where the soil had been tilled conventionally in spring, both with and without shelter. In the laboratory, measured saturated hydraulic conductivity was larger in surface soil cores taken from plots cultivated in the autumn, and average soil temperature measured in the field was also higher under this treatment during the initial stages of plant emergence. This may account for the better plant establishment on the autumn- rather than the spring-cultivated soil. The ultimate aim of this work is to predict the water content and temperature in seedbeds from a knowledge of the intrinsic properties of the soil and the weather. The data are being used to test a mathematical model for this purpose. (North; Patel and Dailey with Dr H. Rowse, National Vegetable Research Station)

Soil mineralogy

Metal oxide mineralogy of soil clays. Iron oxides, even when present in the soil in only small amounts can affect the physical behaviour of the soil. They are commonly studied by difference methods in which diffraction patterns of the soil clay before and after chemical removal of the iron oxides are compared. Although these methods are very sensitive, they are technically difficult to use. An element-specific X-ray diffraction method has now been

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developed. It requires only a single specimen and no chemical treatment, and uses two or more wavelengths. For wavelengths close to an atomic absorption edge (i.e. a spectral transition) scattering is anomalous and depends strongly on wavelength, whereas normally it does not. For example, Fe atoms scatter FeK_α radiation about 40% more strongly than FeK_β radiation, whereas the scattering power of Al, Si and O changes negligibly for these two wavelengths. Comparison of diffraction patterns recorded with FeK_α and FeK_β radiation should therefore enable the peaks from compounds containing Fe to be separated. The feasibility of this method has been tested for the analogous case of compounds containing Co, using CoK_α and CoK_β wavelengths. We have shown that for a Co_3O_4/kaolinite mixture containing as little as 6% Co_3O_4, difference patterns can be obtained in which the kaolinite peaks are almost completely eliminated, leaving only those from Co_3O_4. The method can be applied in principle for any element by selecting two appropriate wavelengths from, say, a synchrotron. On our more modest equipment, however, the technique is restricted to those metals, mainly transition elements, for which X-ray tubes are available. Fortunately iron is one such, and the experiments will be repeated for iron compounds as soon as a new X-ray source is installed. (Wood and G. Brown; Nicholls)

Pedological studies

Stochastic simulation of soil erosion. Two models of soil erosion based on the physics of the processes have been developed. The one of raindrop impact models the dispersion of splash droplets from successive raindrops. The other models the overland flow from the production of run-off and its routing down slope. The two are then combined to give the entrainment and transport of soil in the flow. The models were used to investigate the redistribution of soil particles of different sizes under a variety of conditions. Splash erosion alone simply increased the random variation in particle size distribution. Overland flow, however, imposed spatial auto-correlation in the particle size distribution, the range of which was related to the range of dependence in the surface hydrology. The model simulated gullies at intervals on average equal to this range. (Wright and R. Webster; Munden, with Dr R. P. C. Morgan and Mr D. D. V. Morgan, Silsoe College)

Man-made urban soils. 'Dark earth', a uniform black, man-made soil overlying Roman deposits at many widely separated urban centres, is being investigated to clarify its origin and the reasons for its colour and thickness (usually >1 m). Its age is being determined by radiocarbon dating of various organic constituents and the study of coins, pottery and other artefacts present. At some sites the dark colour results partly from slag and other smelting refuse. Thin sections show it has undergone intense biological disturbance and some illuviation of fine silt as a result of cultivation and structural breakdown. A mineralogical study of its sand fractions showed that it is partly composed of nearby natural soil or sediment, but also contains much finely comminuted anthropogenic material (brick, mortar, pottery, bone, slag). Research is continuing to ascertain the origins of this material. (Catt and Farrington)

Remote sensing

New techniques for measuring radiation from soil and vegetation and for analysing data so obtained provide fresh opportunities for using remote sensing in soil and allied research. Two approaches are being explored, and the following section describes results from the first year's work.

Remote sensing of short-range variation in crops and soil. Within-field variation of soil characteristics is a common cause of yield variation in crops. It presents practical problems in

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farming, such as deciding whether to match crop and husbandry to the most extensive of the soil types present or to make compromises in management. Either choice leads to inefficient use of land, and remote sensing may detect variation at this scale and its effects on crop growth, and so be used to guide management. In 1985 changes in spectral response of three winter cereal crops were measured and related to yield variation and soil difference on 1 m^2 plots. The largest yield differences were found in wheat on a sloping site at Theobalds Park, Hertfordshire, where the soil differences result from successive outcrops of Chalky Boulder Clay, glacial gravel and London Clay on the slope. Smaller yield differences occurred at Brooms Barn, Suffolk (wheat) and Home Farm, Weeting, Norfolk (barley), where the soil variation is caused by periglacial patterns of varying thickness of sand over Chalk. On the last two soils yield variation results mainly from differences in available water capacity, which had little effect during the wet summer of 1985. The changes in spectral response are still being analysed. (Catt and R. Webster; Munden and Ashcroft, with Dr J. C. Taylor, Silsoe College)

Estimating fodder biomass on rangeland remotely from low-level air photography. To make the best use of rangeland in the semi-arid tropics up-to-date maps showing the amount of fodder are needed for large regions. A method for making them has been devised and tested in a part of Botswana. Sample photographs were taken from a height of about 120 m at 1 km intervals, and the herb cover estimated for the sample areas on them. The fodder biomass was measured on a sub-sample of these areas and a calibration equation obtained relating biomass to estimated cover. The spatial distribution of cover was modelled, and cover then estimated for intermediate blocks by kriging to give complete coverage of the region. The kriged estimates of cover were converted to estimates of biomass using the calibration and both cover and biomass were then displayed as isarithmic ('contour') maps. The broad pattern of variation remained fairly similar throughout the year, but the amount of fodder changed substantially. The total amounts of biomass were estimated within acceptable confidence limits for four sub-regions separately. The research was supported by the International Livestock Centre for Africa. (Dancy and R. Webster; Munden, with Mr N. O. J. Abel of the University of East Anglia)

Analytical and techniques

Analytical and isotope sections. The Analytical Section carried out 245 000 analyses, arising from 38 000 samples whilst the Isotope Section did 6000 analyses; of these 18 and 58% respectively were for other departments. (Cosimini, Robertson, Fearnhead, Gregory, Smith, Pope, Kellerman, Thompson, Williams and Armitage)

Replacement of parts in the RF generator of the Inductively Coupled Plasma Emission Spectrometer (ICPES) caused changes in the plasma characteristics which nullified the correction factors painstakingly derived for the effects of Al, Fe, Ca, Mg and Mn on minor elements. These are having to be recalculated for soil extracts. (Fearnhead)

Analysis of samples from the National Soil Inventory has been retarded by the need to derive these new correction factors. Soils from Wales and the adjacent 100 km grid squares together with those from two other squares have been completed. Many digests await analysis. (Cunliffe, Pope, Fearnhead and Thompson)

Automatic data recording. The system described previously (*Rothamsted Report for 1984*, 189) proved effective in the laboratory and was used for 95% of all samples processed there. Further work is needed to develop barcoded labels that can withstand the extremes from immersion in water to high temperatures in the drying ovens and still be machine readable. (Darby, with Verrier and Hipgrave, Computing Unit)

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Staff and visiting workers

P. B. Tinker, Deputy Director and Head of Soils Division, resigned at the end of November to take up the post of Director of Terrestrial and Freshwater Science at the Natural Environment Research Council.

The Department was saddened by the death in March of Gordon Pruden who had worked at Rothamsted for 15 years.

Margo Ewens, J. L. Doran and J. D. D. Mitchell took voluntary premature retirement, N. J. Brown retired and J. A. Currie and D. T. Pritchard left. Caroline Cunliffe resigned in August.

M. J. Goss, D. G. Christian, K. R. Howse, K. G. Henderson, E. T. G. Bacon, C. P. Webster, R. N. LeFevre, D. Brockie, M. R. E. Bulpitt, E. G. Begley all transferred to Rothamsted from Letcombe.

N. W. Pirie gave an 'Opening Lecture' at the International Conference on Leaf Protein Research, at Nagoya, Japan. G. W. Cooke gave a course of lectures in Madrid, an invited paper at the International Symposium 'Potassium in Agriculture' in Atlanta, Georgia, USA, and was Chairman of the 19th Colloquium of the International Potash Institute held in Bangkok, Thailand.

R. A. Leigh spent a six-month study leave partly at the Division of Horticulture Research, CSIRO, Merbein, Australia, and partly at the Department of Botany, University of Maryland, USA. He gave seminars at La Trobe University, the University of Western Australia, the University of California, Davis, Utah State University, E. I. Dupont de Nemours and Company, and Cornell University. S. P. McGrath gave a paper to an EEC Working Party on Environmental Effects of Sewage Sludge Use at Bern and two papers at the International Conference on Heavy Metals in the Environment at Athens. P. B. Tinker lectured at Muncheberg, East Germany and several places in Japan. He attended Conferences on Crop Productivity in Michigan and Washington, USA. M. J. Goss reviewed work in progress for the University of Evora, Portugal, and visited INRA France (with F. Henderson and R. N. LeFevre) for collaborative work. He presented a paper at a Workshop on Soil Compaction and Regeneration at Avignon, France. Both he and D. G. Christian presented papers at the 10th ISTRO Conference at the University of Guelph, Canada. T. M. Addiscott presented a paper at a Workshop on Mechanisms of Ion Transport at the Federal Technical Institute, Zurich in May. R. Webster presented a paper at the Geostatistics Symposium at the Paris School of Mines and lectured at the University of Utrecht. P. C. Brookes presented an invited paper at the Canadian Society of Microbiology Annual Meeting, Halifax, and gave a paper at the Federation of European Microbiologists meeting at Kolle Kolle, Denmark. He lectured at the Institut für Bodenbiologie, Braunschweig, FRG, and the Natural Resource Ecology Laboratories at Colorado State University. K. W. T. Goulding presented an invited paper at the 190th National Meeting of the American Chemical Society in Chicago in September. J. A. Catt gave a lecture at a NATO Advanced Study Institute on Physical and Chemical Weathering in Geochemical Cycles, at Aussois, France, E. G. Youngs presented a paper at the International Symposium on Single and Multiple Fluid Flow through Heterogeneous Permeable Materials at Hamilton, New Zealand. He lectured at research institutes in New Zealand and at the University of Arizona. P. B. Barraclough gave seminars on root growth and nutrient uptake in Hanover, Göttingen and Limburgerhof, FRG.

J. A. Catt accepted an Inaugural Fellowship of the Institution of Geologists. A. C. Wright was awarded a Ph.D. by the Cranfield Institute of Technology, and C. P. J. Shipway continued as a CASE research student until September. Kathryn Dancy transferred to the Entomology Department in September having completed six months work for the International Livestock Centre for Africa. Caroline E. Heijnen of the Agricultural University, Wageningen returned home after six months here, S. J. Kalembassa of the Agricultural and Teachers University, Siedlce, Poland completed three months with us and A. R. Till from

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CSIRO, Australia, departed in October having spent four months here. We welcomed Jedidah R. Onchere from Egerton College, Kenya, for 18 months to work on potassium release from Kenyan soils, C. C. Biddappa from Chinnappa, India, for six months to work on cadmium and nickel uptake by plants, and V. A. Banjoko from the University of Ife, Nigeria, to work for nine months on the effect of zinc-fertilization of soils. E. D. Vance of the University of Missouri was awarded a renewal of his Fulbright-Hays Scholarship for a further 12 months. F. Amijee continued his studies and B. A. Powell and B. M. Smallfield transferred from Letcombe to continue their studies.

PUBLICATIONS

Soil Microbiology Department

Research Papers

Amijee, F., Stribley, D. P. & Tinker, P. B. (1986) The development of endomycorrhizal root systems. VI. The relationship between intensity of infection and development of infection in young leek roots. *New Phytologist* **102,** 293–301.

Buwalda, J. G., Stribley, D. P. & Tinker, P. B. (1985) Effects of vesicular–arbuscular mycorrhizal infection in first, second and third cereal crops. *Journal of Agricultural Science, Cambridge* **105,** 631–647.

Buwalda, J. G., Stribley, D. P. & Tinker, P. B. (1985) Vesicular–arbuscular mycorrhizae of winter and spring cereals. *Journal of Agricultural Science, Cambridge* **105,** 659–657.

(Carr, G. R., Hinkley, M. A., LeTacon, F.), Hepper, C. M., Jones, M. G. K. & Thomas, E. (1985) Improved hyphal growth of vesicular–arbuscular mycorrhizal fungi *Glomus caledonium* and *Glomus mosseae* in the presence of suspension-cultured plant cells. *New Phytologist* **101,** 417–426.

Giller, K. E., (Wani, S. P.) & Day, J. M. (1986) Use of isotope dilution to measure nitrogen fixation associated with the roots of sorghum and millet genotypes. *Plant and Soil* **90,** 255–263.

Giller, K. E. & (Wheeler, B. D.) (1986) Peat and peat water chemistry of a flood-plain fen in Broadland, Norfolk, UK. *Freshwater Biology* **16,** 99–114.

Giller, K. E. & Witty, J. F. (1985) Nodulated legumes grown in N_2-free atmospheres. *Journal of Microbiological Methods* **4,** 179–183.

(Giovannetti, M.) & Hepper, C. M. (1985) Vesicular–arbuscular mycorrhizal infection in *Onobrychis viciifolia* and *Hedysarum coronarium:* host-endophyte specificity. *Soil Biology and Biochemistry* **17,** 899–900.

Harper, S. H. T. & (Lynch, J. M.) (1985) Colonization and decomposition of straw by fungi. *Transactions of the British Mycological Society* **85,** 655–661.

Hayman, D. S. & (Tavares, M.) (1985) Plant growth responses to vesicular–arbuscular mycorrhiza. XV. Influence of soil pH on the symbiotic efficiency of different endophytes. *New Phytologist* **100,** 367–377.

Hepper, C. M. (1985) Influence of age of roots on the pattern of vesicular–arbuscular mycorrhizal infection in leek and clover. *New Phytologist* **101,** 685–693.

(Minchin, F. R., Sheehy, J. E., Ines Minguez, M.) & Witty, J. F. (1985) Characterization of the resistance to oxygen diffusion in legume nodules. *Annals of Botany* **55,** 53–60.

(Misra, A.), Chandler, M. R. & Hepper, C. M. (1985) A comparative study of the structure of effective and ineffective nodules of *Trifolium subterraneum* induced by *Rhizobium trifolii* and *Rhizobium leguminosarum. MIRCEN Journal of Applied Microbiology and Biotechnology* **1,** 83–96.

Sen, R. & Hepper, C. M. (1986) Characterization of vesicular–arbuscular mycorrhizal fungi (*Glomus* spp.) by selective enzyme staining following polyacrylamide gel electrophoresis. *Soil Biology and Biochemistry* **18,** 29–34.

Sen, R. & Hepper, C. M. (1986) Identification of vesicular–arbuscular mycorrhizal fungi using selective enzyme polyacrylamide gel electrophoresis. *Journal of the Science of Food and Agriculture* **37,** 258–259.

https://doi.org/10.23637/ERADOC-1-26

STRIBLEY, D. P. & SNELLGROVE, R. C. (1986) Vesicular–arbuscular mycorrhizas and the phosphorus physiology of plants. *Journal of the Science of Food and Agriculture* **37,** 11–12.

WANG, G., STRIBLEY, D. P., TINKER, P. B. & WALKER, C. (1985) Soil pH and vesicular–arbuscular mycorrhizas. *Ecological Interactions in Soil. British Ecological Society Special Publication No. 4.* Ed. A. H. Fitter. Oxford: Blackwell, pp. 219–224.

GENERAL PAPERS

BERINGER, J. E. & HIRSCH, P. R. (1984) Genetic engineering and nitrogen fixation. *Biotechnology and Genetic Engineering Reviews* **1,** 65–88.

BERINGER, J. E. & HIRSCH, P. R. (1984) The role of plasmids in microbial ecology. In: *Current Perspectives in Microbial Ecology.* Eds M. J. Klug & C. M. Reddy, Washington: American Society for Microbiology, pp. 63–70.

BROOKES, P. C., POWLSON, D. S. & JENKINSON, D. S. (1986) Microbial phosphorus in soils. *Journal of the Science of Food and Agriculture* **37,** 19.

HARPER, S. H. T. (1985) Straw breakdown and toxin production in the field. In: *Straw, soils and science.* Ed. J. Hardcastle. London: AFRC, pp. 10–11.

HAYMAN, D. S. (1985) Effect of plant species, soil and environmental factors on vesicular–arbuscular mycorrhizal (VAM) infection and nutrient uptake. In: *Nuclear techniques to study the role of mycorrhiza in increasing food crop production.* IAEA-TECDOC-338, Vienna: International Atomic Energy Agency, pp. 29–47.

HAYMAN, D. S. (1985) Field inoculation procedures with vesicular–arbuscular mycorrhiza. In: *Nuclear techniques to study the role of mycorrhiza in increasing food crop production.* IAEA-TECDOC-338, Vienna: International Atomic Energy Agency, pp. 175–189.

HAYMAN, D. S. (1986) Mycorrhizae of nitrogen-fixing legumes. *MIRCEN Journal of Applied Microbiology and Biotechnology* **2,** 121–145.

MENGE, J. A., TINKER, P. B., STRIBLEY, D. P. & SNELLGROVE, R. (1985) Inoculum potential—its role in early infection and mycorrhizal efficiency. *Proceedings 6th North American Conference on Mycorrhizae.* Ed. R. Molina. Corvallis, Oregon: Forest Research Laboratory, pp. 394.

(MINCHIN, F. R., SHEEHY, J. E.) & WITTY, J. F. (1985) Factors limiting N_2-fixation by the legume-*Rhizobium* symbiosis. In: *Nitrogen fixation research progress.* Eds. H. J. Evans, P. J. Bottomley & W. E. Newton, Dordrecht: Nijhoff, pp. 285–291.

STRIBLEY, D. P. & SNELLGROVE, R. C. (1985) Physiological changes accompanying mycorrhizal infection in leek. *Proceedings 6th North American Conference on Mycorrhizae.* Ed. R. Molina. Corvallis, Oregon: Forest Research Laboratory, p. 395.

(THOMPSON, J. A., KUMAR RAO, J. V. D. K., RUPELA, O. P.), GILLER, K. E. & DAY, J. M. (1985) Contribution of nitrogen fixation by legumes in the semi-arid tropics. In: *Nitrogen cycling in tropical cropping systems with legumes.* Proceedings of a NIFTAL workshop held at Rodale Research Farms, Emmans, Pennsylvania. Hawaii: NIFTAL.

TINKER, P. B. (1985) Modelling mycorrhizal development. *Proceedings 6th North American Conference on Mycorrhizae.* Ed. R. Molina. Corvallis, Oregon: Forest Research Laboratory, pp. 140–142.

TINKER, P. B. (1985) Rhizosphere microorganisms and plant nutrition with special reference to phosphorus. In: *Proceedings 3rd International Congress on Phosphorus Compounds, Brussels, 1983.* Casablanca: Institut Mondial du Phosphate, pp. 105–120.

WANG, G., STRIBLEY, D. P., TINKER, P. B. & WALKER, C. (1985) Soil pH and vesicular–arbuscular mycorrhizal infection. *Proceedings 6th North American Conference on Mycorrhizae.* Ed. R. Molina. Corvallis, Oregon: Forest Research Laboratory, p. 289.

Soils and Plant Nutrition Department

BOOK

TINKER, P. B. & LAUCHLI, A. (1986) *Advances in Plant Nutrition.* Vol. 2. New York: Praeger Scientific.

https://doi.org/10.23637/ERADOC-1-26

Thesis

Wright, A. C. (1985) *The simulation of the spatial variation in soils using physically-based models of soil erosion.* Ph.D. Thesis, Cranfield Institute of Technology.

Research Papers

Addiscott, T. M. & (Wagenet, R. J.) (1985) Concepts of solute leaching in soils: A review of modelling approaches. *Journal of Soil Science* **36,** 411–424.

Addiscott, T. M. & (Wagenet, R. J.) (1986) A simple method for combining soil properties that show variability. *Soil Science Society of America Journal* **49,** 1365–1369.

(Arkcoll, D. B.), Goulding, K. W. T. & (Hughes, J. C.) (1985) Traces of 2:1 layer-silicate clays in oxisols from Brazil, and their significance for potassium nutrition. *Journal of Soil Science* **36,** 123–128.

Barraclough, P. B. (1986) The growth and activity of winter wheat roots in the field: Nutrient uptakes of high-yielding crops. *Journal of Agricultural Science, Cambridge* **106,** 45–52.

Barraclough, P. B. (1986) The growth and activity of winter wheat roots in the field: Nutrient inflows of high-yielding crops. *Journal of Agricultural Science, Cambridge* **106,** 53–59.

Bateman, R. M. & Catt, J. A. (1985) Modification of heavy mineral assemblages in English coversands by acid pedochemical weathering. *Catena* **12,** 1–21.

Benzian, B. & Lane, P. W. (1986) Protein concentration of grain in relation to some weather and soil factors during 17 years of English winter-wheat experiments. *Journal of the Science of Food and Agriculture* **37,** 435–445.

Brookes, P. C., (Kragt, J. F.), Powlson, D. S. & Jenkinson, D. S. (1985) Chloroform fumigation and the release of soil nitrogen: the effects of fumigation time and temperature. *Soil Biology and Biochemistry* **17,** 831–835.

Brookes, P. C., (Landman, Andrea), Pruden, G. & Jenkinson, D. S. (1985) Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method for measuring microbial biomass nitrogen in soil. *Soil Biology and Biochemistry* **17,** 837–842.

Catt, J. A. (1985) Natural soil acidity. *Soil Use and Management* **1,** 8–10.

Catt, J. A., Avery, B. W., (Green, C. P. & McGregor, D. F. M.) (1985) The nature of the Pebbly Clay Drift at Northaw Great Wood. *Transactions of the Hertfordshire Natural History Society* **29,** (5), 192–203.

Catt, J. A., Gutteridge, R. J. & Slope, D. B. (1986) Take-all distribution and soil type on Chalky Boulder Clay. *Journal of Agricultural Science, Cambridge* **106,** 61–66.

Christian, D. G. (Crees, R. & Dowdell, R. J.) (1985) Yield and uptake of fertilizer nitrogen by direct-drilled winter barley growing on a chalk soil. *Soil Use and Management* **1,** 74–79.

Christian, D. G. & (Miller, D. P.) (1984) *Cephalosporium* stripe in winter wheat grown after different methods of straw disposal. *Plant Pathology* **33,** 605–606.

Currie, J. A. & (Rose, D. A.) (1985) Gas diffusion in structured materials: the effect of tri-modal pore size distribution. *Journal of Soil Science* **36,** 487–493.

Darby, R. J., Widdowson, F. V., Bird, E. & Hewitt, M. V. (1986) The relationship of soil mineral NO_3-N with stem NO_3-N and of fertilizer-N with the amount of nitrogen taken up by winter wheat in experiments testing nitrogen fertilizer in combination with aphicide and fungicides, from 1980 to 1982. *Journal of Agricultural Science, Cambridge* **106,** 497–508.

Ewens, M. & Leigh, R. A. (1985) The effect of nutrient solution composition on the length of root hairs of wheat (*Triticum aestivum* L.). *Journal of Experimental Botany* **36,** 713–724.

Goss, M. J., (Boone, F. R., Ehlers, W., White, I.) & Howse, K. R. (1984) Effects of soil management practice on soil physical conditions for root growth. *Journal of Agricultural Engineering Research* **30,** 131–140.

Jenkinson, D. S., Fox, R. H. & Rayner, J. H. (1985) Interactions between fertilizer nitrogen and soil nitrogen—the so-called 'priming' effect. *Journal of Soil Science* **36,** 425–444.

Johnston, A. E., Lane, P. W., Mattingly, G. E. G., Poulton, P. R. & Hewitt, M. V. (1985) Effects of soil and fertilizer P on yields of potatoes, sugar beet, barley and winter wheat on a sandy clay loam soil at Saxmundham, Suffolk. *Journal of Agricultural Science, Cambridge* **106,** 155–167.

https://doi.org/10.23637/ERADOC-1-26

JOHNSTON, A. E., POULTON, P. R. & LANE, P. W. (1985) Modelling the long-term residual effects of phosphorus residues in soil. *Journal of the Science of Food and Agriculture* **37**, 8–19.

(LAURIE, S. H., TANCOCK, N. P.), MCGRATH, S. P. & SANDERS, J. R. (1985) The influence of complex formation on trace element uptake by plants. *Journal of the Science of Food and Agriculture* **36,** 541–542.

LEIGH, R. A. & JOHNSTON, A. E. (1985) Nitrogen concentrations in field-grown spring barley: an examination of the usefulness of expressing concentrations on the basis of tissue water. *Journal of Agricultural Science, Cambridge* **105,** 397–406.

MCEWEN, J. & JOHNSTON, A. E. (1985) Yield and nitrogen fixation of *Melilotis alba. Field Crops Research* **12,** 187–188.

MCGRATH, S. P. (1985) The effects of increasing yields on the macro and microelement concentrations and offtakes in the grain of winter wheat. *Journal of the Science of Food and Agriculture* **36,** 1073–1083.

MCGRATH, S. P. & CUNLIFFE, C. H. (1985) A simplified method for the extraction of the metals Fe, Zn, Cu, Ni, Cd, Pb, Cr, Co and Mn from soils and sewage sludges. *Journal of the Science of Food and Agriculture* **36,** 794–798.

MCGRATH, S. P., SANDERS, J. R. & ADAMS, T. M. (1985) Comparison of soil solution and chemical extractants to estimate metal availability to plants. *Journal of the Science of Food and Agriculture* **36,** 532–533.

NORTH, P. F. & BROWN, N. J. (1986) A mist irrigation system for use in hydraulic conductivity measurements on small field plots. *Journal of Agricultural Engineering Research* **33,** 51–55.

PIPER, J., (MORRISON, J. A. & PETERS, C.) (1984) The adsorption of carbon monoxide on graphite. *Molecular Physics* **53,** 1463–1480.

PREW, R. D., CHURCH, B. M., DEWAR, A. M., LACEY, J., MAGAN, N., PENNY, A., PLUMB, R. T., THORNE, G. N., TODD, A. D. & WILLIAMS, T. D. (1985) Some factors limiting the growth and yield of winter wheat and their variation in two seasons. *Journal of Agricultural Science, Cambridge* **104,** 135–162.

PRITCHARD, D. T. (1985) A comparison between the diffusivity of gases in soil cores and in soil aggregates. *Journal of Soil Science* **36,** 153–162.

RODGERS, G. A., PENNY, A. & HEWITT, M. V. (1985) Effects of nitrification inhibitors on uptakes of mineralised nitrogen and on yields of winter cereals grown on sandy soil after ploughing old grassland. *Journal of the Science of Food and Agriculture* **36,** 915–924.

(ROTHBAUM, H. P., GOGUEL, R. L.), JOHNSTON, A. E. & MATTINGLY, G. E. G. (1985) Cadmium accumulation in soils from long-continued applications of superphosphate. *Journal of Soil Science* **37,** 99–108.

(TOMOS, A. D.), LEIGH, R. A., SHAW, C. A. & (WYN JONES, R. G.) (1984) A comparison of methods for measuring turgor pressures and osmotic pressures of cells of red beet storage roots. *Journal of Experimental Botany* **35,** 1675–1683.

WEBSTER, C. P. & (DOWDELL, R. J.) (1985) A lysimeter study of the fate of nitrogen applied to perennial ryegrass swards: soil analyses and the final balance sheet. *Journal of Soil Science* **36,** 605–611.

WEBSTER, C. P., (DOWDELL, R. J. & CANNELL, R. Q.) (1985) Uptake of labelled nitrate by roots of winter barley on a direct-drilled or ploughed silt loam soil. *Soil and Tillage Research* **5,** 381–389.

WEBSTER, R. & (OLIVER, M. A.) (1985) Utilisation exploratoire de la géostatistique pour la cartographie du sol dans la forêt de Wyre (G.B.). *Sciences de la Terre, Série Informatique Géologique* **24,** 161–173.

WHITMORE, A. P. & ADDISCOTT, T. M. (1986) Computer simulation of winter leaching losses of nitrate from soils cropped with winter wheat. *Soil Use and Management* **2,** 26–30.

(WICKRAMASINGHE, K. N.), RODGERS, G. A. & JENKINSON, D. S. (1985) Transformations of nitrogen fertilizers in soil. *Soil Biology and Biochemistry* **17,** 625–630.

WIDDOWSON, F. V., DARBY, R. J., DEWAR, A. M., JENKYN, J. F., KERRY, B. R., LAWLOR, D. W., PLUMB, R. T., ROSS, G. J. S., SCOTT, G. J. T. & WOOD, D. W. (1986) The effects of sowing date and of six other factors, on the growth, yield, nitrogen uptake, and on the incidence of pests and diseases of winter barley at Rothamsted 1981–83. *Journal of Agricultural Science, Cambridge* **106,** 551–575.

https://doi.org/10.23637/ERADOC-1-26

WIDDOWSON, F. V., PENNY, A., GUTTERIDGE, R. J., DARBY, R. J. & HEWITT, M. V. (1985) Tests of amounts and times of application on nitrogen and of sequential sprays of aphicide and fungicides on winter wheat, following either beans or wheat, and the effects of take-all (*Gaeumannomyces graminis* var. *tritici*), on two varieties at Saxmundham, Suffolk 1980–83. *Journal of Agricultural Science, Cambridge* **105,** 97–122.

(WINTLE, A. G.) & CATT, J. A. (1985) Thermoluminescence dating of soils developed in Late Devensian loess at Pegwell Bay, Kent. *Journal of Soil Science* **36,** 293–298.

(WINTLE, A. G.) & CATT, J. A. (1985) Thermoluminescence dating of Dimlington Stadial deposits in eastern England. *Boreas* **14,** 231–234.

YOUNGS, E. G. (1985) An analysis of the effect of the vertical fissuring in mole-drained soils on drain performances. *Agricultural Water Management* **9,** 301–311.

YOUNGS, E. G. (1985) Characterization of hydrograph recessions of land drains. *Journal of Hydrology* **82,** 17–25.

YOUNGS, E. G. (1985) A simple drainage equation for predicting water-table drawdowns. *Journal of Agricultural Engineering Research* **31,** 321–328.

GENERAL PAPERS

ADAMS, T. McM. & SANDERS, J. R. (1985) Changes with time in the zinc, copper and nickel concentrations in solutions displaced from two sludge-treated soils. In: *Processing and use of sewage sludge, Proceedings 3rd International Symposium, Brighton, 1983.* Ed. P. L'Hermite. Dordrecht: Reidel, pp. 345–355.

ADAMS, T. McM. & SANDERS, J. R. (1985) The effect of incubation on the composition of soil solution displaced from 4 soils treated with zinc, copper or nickel-loaded sewage sludge. In: *Chemical methods for assessing bio-available metals in sludges and soils.* Eds R. Leschber, R. D. Davis, P. L'Hermite. London: Elsevier, pp. 68–81.

ADAMS, T. McM., MCGRATH, S. P. & SANDERS, J. R. (1985) The effect of soil pH on solubilities and uptake into ryegrass of zinc, copper and nickel added to soils. In: *Heavy metals in the environment,* Vol. 1, Edinburgh: C.E.P. Consultants, pp. 484–486.

ADDISCOTT, T. M. & WHITMORE, A. P. (1986) Looking to the future. *Fertiliser Review 1986,* 13–16.

(BELFORD, R. K.), CHRISTIAN, D. G., (CANNELL, R. Q.) & GOSS, M. J. (1984) Drainage, cultivation and the growth of winter cereals on clay soils. In: *Fonctionnement Hydrique et Comportement des Sols, Comptes Rendus du Colloque,* Plaisir: AFES, 167–174.

BROOKES, P. C. & JENKINSON, D. S. (1985) A direct extraction method for measuring soil microbial biomass nitrogen. *Canadian Society of Microbiologists Annual Meeting Conference Proceedings. Halifax, Nova Scotia, 1985,* p. 67.

BROOKES, P. C., (KLEIN, D. A.), MCGRATH, S. P. & PATRA, D. D. (1985) Effects of heavy metals from sewage sludge on soil microbial biomass and activity. *Canadian Society of Microbiologists Annual Meeting Conference Proceedings, Halifax, Nova Scotia, 1985,* p. 67.

BROOKES, P. C. & MCGRATH, S. P. (1986) Effects of heavy metal accumulation in field soils treated with sewage sludge on soil microbial processes and soil fertility. In: *Microbial communities in soil.* Eds V. Jensen, A. Kjoller & L. H. Sorensen, Amsterdam: Elsevier, pp. 327–343.

BROOKES, P. C. & MCGRATH, S. P. (1985) The response of the soil microbial biomass to heavy metals in soils previously treated with sewage sludge. In: *Microbial communities in soil. FEMS Symposium, Copenhagen, 1985,* p. 46.

BROOKES, P. C., POWLSON, D. S. & JENKINSON, D. S. (1986) Microbial phosphorus in soils. *Journal of the Science of Food and Agriculture* **37,** 19.

BROOKES, P. C., VANCE, E. D. & JENKINSON, D. S. (1985) Measurement of microbial biomass nitrogen in forest soils. *Agronomy Abstracts 1985.* American Society of Agronomy, p. 154.

CATT, J. A. (1985) Soil particle size distribution and mineralogy as indicators of pedogenic and geomorphic history: examples from the loessial soils of England and Wales. In: *Geomorphology and soils.* Eds K. S. Richards, R. R. Arnett & S. Ellis. London: G. Allen & Unwin, pp. 202–218.

CHRISTIAN, D. G. (1984) Effects of straw. In: *Straw incorporation on heavy soils. Workshop papers.* Stoneleigh: National Agricultural Centre, Arable Unit.

https://doi.org/10.23637/ERADOC-1-26

CHRISTIAN, D. G. (1985) Guidelines for straw incorporation. In: *Soils Workshop*. Stoneleigh: National Agricultural Centre.

CHRISTIAN, D. G. (1985) Straw disposal in soil. *B.A.A.S. Annual Meeting. Section M. University of Strathclyde, August 1985*.

CHRISTIAN, D. G., GOSS, M. J., BACON, E. T. G. & SMALLFIELD, B. (1985) Investigating the problems of straw incorporation. In: *Straw, soils and science*. Ed. J. Hardcastle. London: AFRC, pp. 4–5.

CHRISTIAN, D. G., SMALLFIELD, B. M. & GOSS, M. J. (1985) Straw disposal on heavy clay soils. *Proceedings 1985 British Crop Protection Conference—Weeds. Brighton, 1985*, pp. 621–629.

COOKE, G. W. (1986) The interaction between the supplies of water and of nutrients available to crops: implications for practical progress and for scientific work. *Philosophical Transactions of the Royal Society of London* **A316,** 331–346.

CURRIE, J. A. (1984) The physical environment in the seedbed. In: *Aspects of Applied Biology* **7,** *Crop establishment: Biological requirements and engineering solutions*. Wellesbourne: Association of Applied Biologists, pp. 33–54.

GOSS, M. J. & HOWSE, K. R. (1984) Drainage, techniques culturales et comportement hydrique en sol argileux. In: *Fonctionnement Hydrique et Comportement des Sols, Comptes Rendus du Colloque,* Plaisir, France: AFES, 191–202.

JENKINSON, D. S. (1985) How straw incorporation affects the nitrogen cycle. In: *Straw, soils and science*. Ed. J. Hardcastle, London: AFRC, pp. 14–15.

JOHNSTON, A. E. (1985) Incorporating straw as a means of soil improvement. In: *Straw, soils and science*. Ed. J. Hardcastle. London: AFRC, pp. 16–17.

JOHNSTON, A. E. & POWLSON, D. S. (1985) Straw incorporation—what about nitrogen? *Soil and Water* **13,** 12–13.

LEIGH, R. A. & (WALKER, R. R.) (1985) Salt-stimulated ATPase and PPase activities associated with vacuoles from higher plants. In: *Biochemistry and function of vacuolar adenosine-triphosphateses in fungi and plants*. Ed. B. P. Marin. New York: Springer.

LEIGH, R. A. & (WYN JONES, R. G.) (1986) Cellular compartmentation in plant nutrition: the selective cytoplasm and the promiscuous vacuole. In: *Advances in Plant Nutrition,* Vol. 2, Eds P. B. Tinker & A. Läuchli. New York: Praeger Scientific, pp. 249–279.

LEWIS, T. & TINKER, P. B. (1985) AFRC Research and the Environment. *Annual Report AFRC 1984,* pp. 7–18.

MCGRATH, S. P. (1985) Persistence of metals in a long-term sewage sludge experiment. In: *Heavy metals in the environment* Vol. 1, Edinburgh: C.E.P. Consultants, pp. 339–341.

MCGRATH, S. P. & BROOKES, P. C. (1985) Effects of long-term sludge additions on microbial biomass and microbial processes in soil. In: *Factors influencing sludge utilisation practices in Europe*. Eds H. Haeni, R. D. Davis & S. Gupta. London: Elsevier.

MCGRATH, S. P. & BROOKES, P. C. (1985) Metals do persist. *Crops Weekly* 22 March 1985.

PENNY, A., WIDDOWSON, F. V., JENKYN, J. F. & PREW, R. D. (1985) Effects of nitrogen rates and times and their interactions with other husbandry factors in winter cereals. In: *Better use of nitrogen—the prospects for winter cereals*. National Agricultural Conference. Stoneleigh: National Agricultural Centre.

PIRIE, N. W. (1985) Comments on the importance of green vegetables. *Qualitas Plantarum: Plant Foods in Human Nutrition* **35,** 73–80.

PIRIE, N. W. (1985) Extracted leaf protein in British agriculture. *Nature* **315,** 720.

PIRIE, N. W. (1985) Leaf protein extraction deserves more attention. *Milling* **169,** 15–16.

TINKER, P. B. (1985) Crop nutrients—control and efficiency of use. In: *Technology in the 1990s: Agriculture and Food*. Eds Sir Leslie Fowden and Sir Kenneth Blaxter. *Philosophical Transactions of the Royal Society of London* B**310,** 175–191.

TINKER, P. B. (1985) Introduction. In: *Straw, soils and science*. Ed. J. Hardcastle. London: AFRC, p. 1.

TINKER, P. B. (1985) Site-specific yield potentials in relation to fertilizer use. In: *Nutrient balances and fertilizer needs in temperate agriculture*. Ed. A. von Peter. Berne: International Potash Institute. pp. 193–208.

TINKER, P. B., ADDISCOTT, T. M., DARBY, R. J., WHITMORE, A. P., WIDDOWSON, F. V. & (VAIDYANATHAN, L. V.) (1985) Predicting the nitrogen requirement of cereals. In: *Better use*

https://doi.org/10.23637/ERADOC-1-26

of nitrogen—the prospects for winter cereals. National Agricultural Conference, Stoneleigh: National Agricultural Centre.

VANCE, E. D., BROOKES, P. C. & JENKINSON, D. S. (1986) Interpretations of microbial biomass measurements in forest soils. *Agronomy Abstracts 1985*. American Society of Agronomy, p. 226.

VANCE, E. D., BROOKES, P. C. & JENKINSON, D. S. (1985) Why the chloroform fumigation method does not work in acid soils. *FEMS Symposium, Copenhagen, 1985*, p. 35.

WEBSTER, R. (1985) Quantitative spatial analysis of soil in the field. *Advances in Soil Science* **3**, 1–70.

WEIR, A. H. & EDWARDS, B. S. (1985) A demountable mobile crop shelter for small-scale field experiments. In: *Aspects of Applied Biology, 10, Field trial methods and data handling*. Wellesbourne: Association of Applied Biologists, pp. 499–507.

WHITMORE, A. P. & ADDISCOTT, T. M. (1985) Computer simulation of changes in soil nitrogen during winter under a crop of winter wheat. In: *Assessment of nitrogen fertilizer requirement*. Eds J. J. Neeteson & K. Dilz. *Proceedings 2nd meeting of the N.W. European Study Group for the Assessment of Nitrogen Fertilizer Requirement. Institute for Soil Fertility, Haren (Gr.)*, pp. 133–137.

https://doi.org/10.23637/ERADOC-1-26