ROTHAMSTED RESEARCH

Report for 1982 - Part 1

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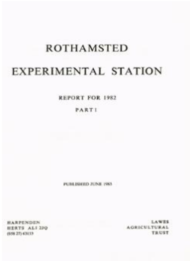
ROTHAMSTED

EXPERIMENTAL STATION

REPORT FOR 1982

PART 1

Soils and Plant Nutrition Department

P. B. Tinker

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Introduction

The largest effort in the Department continues to be on yield variation and the related work on nitrogen. This work is now at the stage where we are attempting to define the reasons for the measured variations of yield between sites. As part of this, our interest in the potential yield losses due to water stress is increasing, though we do not believe that they are necessarily large. However, uncertainty on this point has persisted for many years, and it appears timely to attempt to get clear answers to this question on major soil types. For this reason our work under rain shelters is growing. Work on root-soil relations has measured the water relations of root hairs, as part of the study of their value to roots.

The 'Nitrogen-Balance' method of predicting the best rate of nitrogen discriminated between sites as well as in previous years, but slightly underestimated the best dressings. This method, in association with computer modelling of soil nitrogen changes, offers the possibility of a fully integrated method of predicting nitrogen requirements on individual fields, and tests of it on a range of sites have started in association with ADAS. In the work with ^{15}N, an important result is the finding of a loss of applied fertilizer soon after application to wheat in spring, and that the size of the loss is related to the rainfall shortly after the application. Other work with ^{15}N has explained the difference in the 'efficiency' of nitrogen fertilizer as measured by ^{15}N and by conventional means, which needs careful attention in view of the economic and political implications of this subject.

There are now few significant practical problems relating to potassium fertilizers, but very large sums are saved by the ability of some soils to release potassium to crops. To define this property more closely soils from a number of long-term field experiments have been used to test the cation exchange resin extraction method developed here. It correlates well with the long-term off-take of potassium, but in some tests a much simpler, newly developed acid extraction technique was even better.

A great deal of work on mycorrhizas has been reported this year, including a 3-year study of infection in cereal crops, where it appears to be of moderate importance for phosphorus nutrition. The work now in progress is giving a much clearer fundamental understanding of the processes involved in spread of infection.

The programme on metal toxicity in sewage sludge is developing rapidly. A particular advantage to this work is the old Market Garden experiment at Woburn, which received metal-containing sludges up to 1961. We are now testing the behaviour and availability of the residual metals, on a site which is almost unique in this type of work. It is hoped that there may be the opportunity to carry out trace element analyses on samples from the Soil Survey's programme, and pilot work for this has shown interesting and potentially useful correlations between total and 'available' trace metal levels in certain soil series.

The mathematical approach to spatial variation continues to be applied to several facets of the Department's work, including soil structure and leaching processes. Much pedological work is reported this year, with stress on pedogenesis of soils affected by loess deposition. Two studies are relevant to archaeology, one being on a 'dark earth' layer found on urban centres of the post-Roman period.

Studies on yield variation

Our studies on factors affecting yield and the capacity of different soils to produce high yields continued. A major problem in comparing soil types is that the weather is almost always different when sites are separated. For this reason we have concentrated on sites grouped within 25 miles of Rothamsted, with the exception of Saxmundham, which is included because of our extensive experience with the difficult Beccles series soil.

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However, even small distances between sites can cause rainfall to be significantly different, and this year we compared two sites close together on Woburn farm with very different soils.

A further short-distance comparison was made at Rothamsted. In previous years three wheat trials had followed potatoes, but in 1982 oats and barley were the precursor crops, to allow a test of the effects of take-all (see Multidisciplinary section, p. 19). To maintain continuity of results, and to allow a comparison between the very different nitrogen regimes established after the different precursor crops, we established a smaller wheat experiment following potatoes in 1982, on the same (Batcombe) series. We thus had eight sites in all: two at Rothamsted, two at Woburn, and the usual four 'outside' sites.

The best yields were generally lower than last year, and only the Hexton and Saxmundham sites had treatment combinations with over 10 t grain ha^{-1}. This is puzzling, because the national yield was greater in 1982 than 1981; however, yields in the Hertfordshire area were not particularly good.

The aim of obtaining more definite information on the yield loss due to drought is an important part of Four-Institute Yield Variation programme. As part of this, an attempt is being made, in collaboration with the Soil Survey, to determine the overall national picture from existing records and a simple drought model (p. 260). Much greater stress is also being placed on work under static shelters (p. 259) in a coordinated programme with work in the mobile shelter on Little Knott (see Physics Department Report). This has given important information on rooting and water extraction during drought, but the loss of radiation under a static shelter must always make this an imperfect research tool, and we are now investigating the possibilities of cheap mobile shelters.

Comparisons between sites

Wheat following oats, barley or potatoes, at Rothamsted. During 1979–81 the wheat in the multifactorial experiments at Rothamsted was grown after potatoes, but in 1982 it followed either barley or oats to assess the importance of soil-borne diseases. A smaller wheat experiment following potatoes was made in 1982 on a different field, but on the same Batcombe series. Three factors, sowing date, N rate and N timing were common to this experiment and to the multifactorial one, and the variety on both was Avalon. Although amounts of fertilizer N were different on the two sites they were calculated to give the same total N supply after taking into account soil mineral N (p. 261).

The comparison of these crops following oats, barley and potatoes is interesting. The lower yields following barley are presumably due to take-all (see p. 258). It is remarkable that the early growth after potatoes was the best, by up to 70%, but that the crop following

TABLE 1

Yields of wheat grain at 85% DM t ha^{-1}

(data are for plots receiving fungicide)

Field Previous crop	Gt. Knott I Oats		Gt. Knott I Barley		Pastures Potatoes	
Sowing date	22/9	22/10	22/9	22/10	22/9	22/10
			N applied early			
N1	8·35	8·15	4·67	5·25	7·85	7·15
N2	8·66	8·93	6·16	6·28	7·87	7·76
			N applied late			
N1	7·66	7·90	4·71	4·91	7·64	6·88
N2	8·11	8·60	4·36	4·83	8·26	7·56

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oats caught up, and its best yield (Table 1) exceeded that following potatoes by 0·6 t ha^{-1}. In almost all cases the best yields were obtained with the N_2 rate, as the 'balance method' of prediction appeared to underestimate demand slightly this year (see p. 262). At the N2 rate, the crop after potatoes followed the pattern of previous years (also after potatoes), with the best yields being for late applied N for the early-sown crop, but early applied for the late sown. The crop after oats was different, with early applied N best for both sowings, but especially for the early-sown. The soil contained much more NO_3-N in winter and in spring after potatoes than after oats, and there was more NO_3-N in the sap of the wheat stems. The response to the second rate of N was almost exactly the same after both oats and potatoes, but there may have been a remaining N deficiency after potatoes, as yields were still rising slowly at 175 kg N ha^{-1}.

We are awaiting the detailed soil and crop analyses for nitrogen to see if they can explain these results. It may be important that much of the N supply after potatoes was distributed down the profile, as it was residual N, whereas that for wheat after oats was almost all near the surface, as it was applied as fertilizer. (Penny, Widdowson, Darby and Hewitt)

Wheat on a sandy versus wheat on a clay soil, at Woburn. Six factors were tested on winter wheat following potatoes on two very contrasted soils (Table 2).

These data, together with growth analysis, have yet to be studied in detail (see Multidisciplinary Section of the Annual Report). Table 3 shows comparable grain yields from three of the factors tested both in the Rothamsted and in the Woburn experiments, mainly to show the similarity of yield and the different effect of irrigation on the four sites. As usual, irrigation on the Rothamsted sites caused a loss in yield in almost all

TABLE 2

The effect of six factors on grain yield, t ha^{-1} at 85% DM, of Avalon winter wheat at Woburn, in 1982

Soil:	Field: Butt Close sandy, Cottenham series	Broad Mead sandy-clay, Blithe series
Factor tested		
1. Sowing date		
23 September	7·57	8·22
23 October	7·43	7·76
2. Total N kg ha^{-1}		
N1	(120)* 6·69	(30)* 7·67
N2	(180) 8·32	(90) 8·31
3. N time		
Early	7·55	7·97
Late	7·45	8·01
4. Winter N kg ha^{-1}		
Without	(0)* 6·91	(0)* 7·85
With	(60) 8·09	(30) 8·13
5. Irrigation		
None	7·16	8·00
Full	7·84	7·98
6. Aldicarb (5 kg ha^{-1} to seedbed)		
Without	7·40	7·72
With	7·60	8·26

* Figures in parentheses are the rates of N in that experiment

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TABLE 3

Yields of wheat grain at 85% DM, t ha⁻¹

(data are for plots receiving aphicide and fungicide)

	Rothamsted				Woburn			
Field	Gt. Knott I		Pastures		Broad Mead II		Butt Close I	
Previous crop	Oats		Potatoes		Potatoes		Potatoes	
Sowing date	22/9	22/10	22/9	22/10	23/9	23/10	23/9	23/10
	Not irrigated							
N1	7·78	8·36	7·93	7·07	7·60	7·52	6·57	6·20
N2	8·60	8·62	7·89	7·75	8·56	8·30	8·11	7·76
	Irrigated							
N1	7·16	7·54	7·56	6·96	7·94	7·60	7·20	6·78
N2	7·78	8·18	8·24	7·58	8·78	7·60	8·40	9·00

N rates (kg ha^{-1}): 150 and 220, Great Knott; 70 and 140, Pastures; 45 and 105, Broad Mead; 150 and 210, Butt Close

treatments, and also on average. Effects on the sandy clay at Woburn were generally very small increases or a decrease. On the sandy soil at Woburn there were positive responses to irrigation, particularly at N1 rate for the early-sown wheat and at the N2 rate for the late-sown wheat. This confirms much other information suggesting that in an averagely wet year only crops on sands or coarse sandy loams respond to additional water. The shelter work (p. 259) indicates that even when crops are stressed by complete droughting, on this Batcombe soil they obtain sufficient stored water to suffer only a small yield loss. (Widdowson, Penny, Darby and Hewitt, with Welbank and Thorne, Botany Department)

Field experimentation on outside sites. In addition to the experiments made at Rothamsted and Woburn, less complex experiments were again made at Saxmundham in Suffolk and on the same private farms used in 1981. Each tested a combined treatment of fungicides and systemic aphicide, with none and four levels of nitrogen fertilizer applied either singly or as a divided dressing (on two varieties, and following two different previous crops at Saxmundham). The rates of nitrogen, chosen to give the highest yield at the third level of N, were based on previous cropping and soil analysis for mineral N. The varieties used were Avalon (3rd cereal) sown 31 October at Billington, Norman (11th wheat) sown 3 November at Maulden, Longbow (1st wheat) sown 15 October at Hexton, and Avalon and Norman (both 1st and 2nd wheats) sown 13 October at Saxmundham.

Regular measurements of rainfall, dry matter and nitrogen accumulation, disease incidence, soil water content, soil mineral nitrogen and plant stem nitrate were made on all sites except Saxmundham where fewer stem nitrate and no soil water measurements were made. Grain yields were measured at all sites. Some of the data are still to be processed. The main results are given below.

Yield and dry matter. Dry matter accumulation in all experiments was exponential from the end of March to anthesis when it became linear before declining in mid-July. The patterns of dry matter accumulation were similar at Billington and Maulden, giving maximum dry matter yields of 12·1 t ha^{-1} at Billington and 13·4 t ha^{-1} at Maulden. The accumulation rate at Hexton was 30% larger for the same period, giving a maximum DM yield of 17·0 t ha^{-1} in late July. At Saxmundham, following winter beans, dry matter yields of 15·6 and 15·5 t ha^{-1} were achieved by Norman and Avalon respectively. How-

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ever, when they followed wheat the maximum DM yield differed considerably between varieties; Norman achieved 12·0 t ha^{-1} whereas Avalon accumulated only 8·9 t ha^{-1}.

The best combination of treatments produced grain yields of 11·06 t ha^{-1} at Saxmundham (mean of two varieties, after beans), 10·17 t ha^{-1} at Hexton, 8·21 t ha^{-1} at Maulden, 8·11 t ha^{-1} at Saxmundham (mean of two varieties, after wheat) and 7·63 t ha^{-1} at Billington. Applying the nitrogen fertilizer in two dressings gave significant improvements in yield of 0·60 and 0·28 t ha^{-1} at Billington and Maulden.

Plant numbers m^{-2} in March were only 114 at Hexton, and 155, 216, 205 and 191 at Maulden, Billington and the two Saxmundham sites respectively. The crops compensated for low plant numbers, and by anthesis the ear numbers m^{-2} stabilized at 286, 351, 380, 333 and 426 at Hexton, Maulden, Billington and the two Saxmundham sites respectively. (Darby, Widdowson, Penny and Hewitt)

Diseases. Foliar pathogens were not prevalent on any site, mildew was present in trace amounts at Maulden and Hexton and was slight at Billington where *Septoria* was also slight. Eyespot and sharp eyespot were present but not severe at any site. Take-all was common at Maulden and Billington, nearly half the plants were infected though mostly only slightly so. The combined fungicide and aphicide spray treatments provided a good control of leaf diseases but failed adequately to control *Botrytis* and *Fusarium* spp., which infected the ears of many crops in Hertfordshire and Bedfordshire and to a much lesser extent in Suffolk. On average the disease control programme prevented the loss of between 0·26 and 0·90 t ha^{-1}. (Prew, Field Experiments Section, with Darby)

TABLE 4

Yield of grain at 85% DM, t ha^{-1}

Experiment	Hexton		Billington		Maulden	
Aphicide/Fungicide N (kg ha^{-1})	None	Sprayed	None	Sprayed	None	Sprayed
Nil	8·26	8·59	3·53	3·78	4·43	4·55
70	9·07	9·80	—	—	—	—
100	9·16	9·93	—	—	6·68	7·57
130	9·19	10·08	6·63	6·93	6·83	7·71
160	9·05	10·15	6·57	6·89	6·85	7·84
190	—	—	7·00	6·89	6·76	8·00
220	—	—	6·97	7·50	—	—

Experiment	Saxmundham			
Previous crop	W. Wheat		W. Beans	
Aphicide/Fungicide N (kg ha^{-1})	None	Sprayed	None	Sprayed
Nil	2·32	2·45	7·54	7·91
70	—	—	9·19	9·59
100	—	—	9·43	10·25
130	6·14	6·35	9·90	10·55
160	6·37	6·90	9·61	10·78
190	6·85	7·41	—	—
220	7·47	7·57	—	—

Nitrate N in wheat stems. This measurement has been shown to relate to the concentration of nitrate N in the soil. It is regarded as an indication of the immediate plant N status and as a possible method of determining whether N fertilizer is needed. The contrast between potatoes and cereals as preceding crops showed clearly in the Rothamsted experiments. The average after cereals was 810 $\mu g\ g^{-1}$ in February, declining rapidly to 280 (8 March) and 5 (12 April) when no fertilizer N was given. In contrast, after potatoes the value declined on the same dates, from 920, to 830 and 340 $\mu g\ g^{-1}$.

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However, the addition of 100 kg N ha^{-1} to wheat after potatoes only raised the level to 550. On the Woburn experiments values declined in the same way, and reached zero where no N was applied, on 2 April on Butt Close and 12 May on Broad Mead. On outside sites they reached zero on 30 April at both Billington and Maulden, but not until 8 July at Hexton. Fertilizer N application increased these levels for a time at all sites, and they remained above 200 $\mu g\ g^{-1}$ at Billington and Hexton as late as 22 July. The relatively poor yields at Billington could not therefore be due to shortage of nitrogen. (Darby, Widdowson and Bird)

Winter wheat crop model. The computer model described last year (*Rothamsted Report for 1981*, Part 1, 248), with the addition of a new grain-growth sub-model, was tested against crop growth from the 1979, 80 and 81 WW/3 factorial wheat experiments (*Rothamsted Report for 1979*, Part 1, 17, *for 1980*, Part 1, 17, and *for 1981*, Part 1, 19). The data were for early- and late-sown crops of Hustler winter wheat, excluding those plots where disease or lack of N or water were thought to have reduced yields.

The periods between growth stages (phases) were compared for simulated and observed values for the six crops. When grouped into early- and late-sown crops the average simulated phase lengths were within 2 days of the observed for sowing to emergence, emergence to double ridge, double ridge to anthesis and anthesis to maturity. Thus the model simulates well the shortening of certain phases with late sowing on average, but it is somewhat less successful in predicting individual crop development.

Tiller growth was simulated using an assumed shoot production rate and an emerged plant population of 250 plants m^{-2}. The numbers of ear-bearing shoots at anthesis for early- and late-sown crops, 641 and 617 m^{-2}, exceeded observed numbers by 12%.

The canopy leaf area was simulated by growing leaves to maximum sizes on each main shoot and tiller. For early-sown crops the simulated leaf areas slightly exceeded the observed leaf areas, whereas those of the late-sown crops fell a little short of the observed. This is probably the first time that a wheat crop canopy has been simulated in this detailed way, and at present there are very few crop data on which to base the model.

The simulated total weights of the mature crops depend on the success of modelling the growth of the leaf canopy. In fact agreement was good; the average weight of the early-sown crop at maturity, 2035 g m^{-2}, exceeded the observed weight by 270 g m^{-2}, whereas the late-sown, 1541 g m^{-2}, was 110 g m^{-2} less than the observed.

In the new grain-growth sub-model, ears were grown during the period of 18 days before anthesis by increasing linearly from 0 to 100% the proportion of daily net assimilate diverted to them. After anthesis all new net photosynthate went to grain production, and, in addition, a fixed proportion of stem and leaf weight at anthesis was regarded as a pool for either grain growth or maintenance respiration. An interesting consequence of linking a temperature-dependent grain growth rate with the thermal time total for grain growth is that the temperature during the period from anthesis to maturity sets the maximum grain weight. The average simulated grain yield of the early-sown crops was 893 g m^{-2}, 7% greater than observed, whereas that of the late-sown, 768 g m^{-2}, was 3% less.

The model has thus combined initial data from many wheat crops to produce good simulation of the growth of crops that have a narrow range of yields. We will now model against data from a wider range of conditions, and incorporate limitations to growth from shortages of water and N. (Weir and Rayner with Dr P. L. Bragg, ARC Letcombe Laboratory and Drs J. R. Porter and W. Day, Long Ashton Research Station)

Effects of water shortage

The effects of drought on growth of winter wheat under a fixed shelter. The mobile shelter sited on Little Knott I was used this year to study the effects of drought on

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winter wheat (see p. 176). An adjacent area was used for root and shoot growth measurements of the same variety of wheat, Avalon, and with similar main treatments. The soil is a silty variant of the Batcombe series, and is thus suitable for detailed soil and root measurements, but it also has a large water holding capacity.

The crop was covered at the end of March with a fixed polythene shelter to exclude all rain. Temperatures under this shelter stayed near ambient, but the shelter intercepted much light, so that the crop received only 65% of the incident radiation, which probably caused the 20% reduction in dry matter yield below that under the mobile shelter.

The soil in one half of the experimental area was brought back weekly to within 25 mm of its drained capacity by irrigation, and the other half received no water. Top growth and roots were sampled, and soil water contents monitored with a neutron moisture meter. At harvest in early August grain yields were 520 and 490 g m^{-2} (6·1 and 5·8 t ha^{-1} at 15% moisture) for irrigated and droughted crops respectively.

The irrigated crop transpired 295 mm of irrigation water and a further 40 mm of stored soil water, mainly from the upper 0·7 m of the profile, but with small amounts extracted down to a depth of at least 1·6 m. The droughted crop extracted 220 mm of stored water from the soil. Water was extracted down to a depth of at least 2·0 m, although only 3 mm came from between 1·8 and 2·0 m, and 24 mm from below 1·4 m. Water was extracted from near the surface first, and the soil between 1·6 and 1·8 m did not start to supply the crop with water until mid-June, and that below 1·8 m not until the beginning of July.

Roots had penetrated to at least 1 m depth, were 6.4 km m^{-2} in total length and weighed 44 g m^{-2} by March. Sixty per cent of these roots were between 0 and 0·2 m depth. By anthesis, roots had penetrated to 1·8 m for both treatments, but 45% of root length was between 0 and 0·2 m depth and only 8% below 1·0 m. Droughting reduced root weights by 8%, from 163 to 150 g m^{-2}, and lengths by 16%, from 26.7 to 22.4 k m^{-2}. Most of this reduction occurred in the top 0·4 m of the soil, where specific root length of the droughted crop was smaller. Below 0·4 m root growth was very similar for the two treatments and there was no evidence of compensatory root growth at depth by the droughted crop. (Barraclough, Kent, Norrish and Weir)

Yield loss assessment in winter wheat with a model of drought. It has been proposed (Thomasson (1979), *Soil Survey Technical Monograph* 13) that the soil and water relations of a crop can be summarized by (water available in the profile for that type of crop, AP) – (the maximum potential soil moisture deficit for an appropriate period, MD). This was tested on reported wheat yields from a group of Experimental Husbandry Farms for a period including the very dry year 1976. In wet and average years the winter wheat yield was very variable, but only weakly related to AP-MD for these farms. In dry years the yield tended to fall as AP-MD fell. This 'yield loss' is rather larger (in t mm^{-1} of water), than estimates of maximum theoretical benefit from irrigation.

A more extensive study of soil supply and wheat growth has been started to take advantage of new sources of spatially defined information, and better methods of handling such information, that are just becoming available. These include the transfer of agricultural census information reported by parishes to national grid defined squares, and the 1:250 000 Soil Survey countrywide map which will be published in spring 1983 and is currently being prepared in a computer-readable form. This will give the soil grouping, for any location, from which profile-available water can be estimated.

With this information we aim to identify that part of the area sown to wheat that would be likely to suffer loss from drought in any specified fraction of years, and thus to assess the effect on the national crop. (Rayner, with Thomasson, Soil Survey)

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Investigations on nitrogen

Nitrogen requirement prediction

Mineral nitrogen in soils under winter wheat during winter and spring. Soils on all eight sites in the Yield Variation Group (see p. 28) were sampled to 90 cm depth at crop emergence in autumn, and at least twice in spring, to measure NH_4-N and NO_3-N. On 6 October the soils under the September-sown wheat on Rothamsted sites contained only 20 kg NO_3-N ha^{-1} after oats, but 156 kg ha^{-1} of NO_3-N after potatoes. There was more NO_3-N under October-sown that under September-sown wheat until 15 April by when, 40 kg NO_3-N ha^{-1} remained under the October-sown wheat following potatoes, but little under the others.

As before, NO_3-N accumulated in the lower horizons under the October-sown, but not under the September-sown wheat, presumably because the roots of the latter extracted it from depth. Again, on a clay loam, early sowing increased uptake and so diminished the chances of NO_3-N being lost either by leaching or by denitrification during winter.

At Woburn much rain fell soon after the September sowing, and on 6 October only 64 kg NO_3-N ha^{-1} were found in the sandy soil, whereas there were 250 kg NO_3-N ha^{-1} in the sandy clay. At Saxmundham and at Hexton, under the wheat following a legume, soil NO_3-N contents in November were large (96 and 136 kg NO_3-N ha^{-1} respectively), but declined to 74 kg NO_3-N ha^{-1} at Hexton and 22 kg NO_3-N ha^{-1} at Saxmundham in April. Where wheat followed one or more previous cereal crops, two of these soils contained only 30 kg NO_3-N ha^{-1} in December, but 110 kg NO_3-N ha^{-1} was found at Maulden, where old pasture had been ploughed 11–12 years ago. However, in spring amounts after cereals varied between 20 and 60 kg NO_3-N ha^{-1}.

These results are now being modelled with the improved leaching/mineralization/crop uptake model described below. First indications are that it will be at least as successful as last year, in that the mineral N in the profile in spring, and that taken up by the crop, can be modelled starting with information on nitrate in the soil in autumn. (Widdowson, Darby and Bird)

Improved leaching and nitrogen requirement prediction models. The leaching model based on the concept of mobile and immobile soil water phases (*Rothamsted Report for 1976*, Part 1, 87) was incorporated in the model for prediction of nitrogen in the soil profile under winter wheat (*Rothamsted Report for 1981*, Part 1, 251–252). The original form of the leaching model assumed that the profile had been recharged with water at the start of the run and did not dry out appreciably during the winter. Running the model from the time of harvest of the preceding crop may have the advantage of elminating the need for autumn sampling, because it may be sufficient to assume that little mineral N is left after a cereal, and that standard values can be found for other crops. The leaching and prediction models have therefore been modified so that they are able to start with a dry profile, and the latter has also been modified to allow for water removal through the roots and for the effects of soil drying on N uptake and mineralization of soil organic N.

The original form of the leaching model assumed that, after the downward movement in the mobile phase, the solute concentrations in the mobile and immobile phases were equalized. A more correct but complicated form (*Rothamsted Report for 1979*, Part 1, 235) modelled the movement between the phases explicitly as diffusion from aggregates, and this has made it possible to predict how close to equilibrium the solute concentrations would become, and to use these values in the simpler leaching model and in the prediction model. (Addiscott and Whitmore)

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Nitrogen balance system. The third component of the prediction system (*Rothamsted Report for 1981*, Part 1, 250) is the calculation of the best rate of N fertilizer from the known levels of mineral N in the soil, crop N content, and crop yield aimed for. Again, this year all our Yield Variation trials received rates of N designed so that the penultimate one was expected to give the maximum yield. This was extremely successful for non-sprayed crops (Table 4, p. 258), but crops sprayed with fungicide responded to more N, and for these the prediction was low by 20–30 kg ha^{-1}. The efficiency of added N appears have been a little low this year, for reasons we do not yet understand.

N concentration of grain and grain yield in recent winter-wheat experiments in England and Belgium. Our graphical method of presentation of grain-N/yield relationships (Benzian & Lane, *Journal of the Science of Food and Agriculture* (1979), **30,** 59–70) was applied to results for modern high-yielding varieties grown in England and Belgium in 1980 and 1981. Yields exceeding 10 t ha^{-1} were obtained on many of the English pesticide-treated plots and at one of the Belgian sites. The envelope curve on our earlier graphs of grain-N% plotted against yield included most of the recent data points, but not some of the very large yields with low grain-N% values. The largest grain-N uptakes were 180 to 190 and 170 to 180 kg ha^{-1} in the recent Rothamsted and Belgian experiments respectively, compared with 160 and 170 kg in the older experiments.

A near-linear relationship between grain-N% and amounts of fertilizer N was again observed in these experiments, with about 38 kg of added N needed to increase grain-N concentrations by 0·1%. (Benzian, Darby and Widdowson, with Lane, Statistics Department, and Ir L. M. J. Verstraeten, Katholieke Universiteit of Leuven, Belgium)

Studies with ^{15}N labelled fertilizers

The effect of additions of inorganic fertilizer N on the supply of inorganic N from the soil. Experiments with ^{15}N labelled fertilizers often show that the addition of fertilizer increases the uptake of N from the soil reserve by the crop, sometimes called a 'priming effect'. We are investigating this effect in soils incubated without plants, in pot experiments with plants and in the field. Only the first two are reported this year.

After ^{15}N-labelled $(NH_4)_2SO_4$ was added at the rate of 58 μg N g^{-1} soil and incubated for 10 days the soil had contributed 4·3 μg *un*labelled NH_4-N per g soil; the control soil to which no NH_4-N had been added produced only 0·3 μg, giving a 'priming effect' of 4·0 μg. However, this was only an apparent effect, as the *net* mineralization of N by the soil receiving NH_4-N was slightly less than that of the control. The 'priming effect' arose because labelled NH_4-N substituted for unlabelled NH_4-N that would otherwise have been immobilized. Similar results were obtained in soils that were fumigated to prevent nitrification. (Shen, Pruden and Jenkinson)

Spring wheat was grown in a pot experiment in two Batcombe series soils, of which one had been under permanent grass, and the other, originally also under grass, had been fallowed for the last 22 years. The two soils thus differed greatly in biological activity and ability to immobilize N. ^{15}N-labelled $(NH_4)_2SO_4$ was mixed into the soil immediately before sowing to maximize a possible 'priming effect'. Recoveries of ^{15}N in the crop and soil were between 93 and 101%, with a tendency for the best recoveries to be found in the grassland soil. There was a large positive 'priming effect' in both soils; addition of labelled N at the top rate roughly doubled the uptake of unlabelled N from each soil. The grassland soil gave the largest priming effect but also immobilized most N, consistent with the conclusion that the effect was 'apparent', caused by labelled N standing proxy for unlabelled N that would otherwise have been immobilized, and not by a real increase in the quantity of N released by the soil.

The effects of immobilization can also be seen in calculations of efficiency of uptake.

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Thus the efficiency of uptake of added N by herbage and roots (calculated from the difference in total N uptake by the treatments receiving 242 and 4·9 mg of fertilizer N per pot) was 85·1% in the fallow soil and 94·8% in the grassland soil. Measured by uptake of ^{15}N, it was much less; 74·0 and 61·7% respectively. Effects of this nature may be important, and must be taken into account in interpreting the results from experiments with ^{15}N labelled fertilizers. (Hart, Jenkinson, Johnston, Powlson and Pruden)

Losses of ^{15}N labelled fertilizer N applied to winter wheat. In each of the last 3 years ^{15}N-labelled fertilizer has been applied to microplots within two winter wheat experiments at Rothamsted. In the multifactorial wheat experiment wheat followed a break crop and ^{15}N-labelled fertilizer was applied to high-yielding plots receiving optimum pest and disease control. On Broadbalk, ^{15}N was applied to areas where wheat has been grown every year since 1966.

In both sets of experiments the loss of fertilizer N (i.e. that not recovered in crop and topsoil) was greatly influenced by the amount of rain falling shortly after application (Table 5). Over all the results, the loss of fertilizer N can be related to spring rainfall by the regression equation

$$y = 0{\cdot}26x + 6{\cdot}95$$

where y = percentage of fertilizer N not present in crop or topsoil (0–23 cm)
x = mm of rain in the 4 weeks following application of N.

This equation accounts for 74% of the variation in N loss. Sampling to 70 cm on some plots showed that little ^{15}N was below 23 cm, so the loss must be due to denitrification or to leaching of nitrate below 70 cm or both. Current work is aimed at assessing the relative importance of these two processes.

The results indicate there is more risk of loss by giving spring N fertilizer early rather than late. However, in 1981 the loss from the early application of N to the multifactorial experiment was less than later application to the Broadbalk experiment, which was followed by a wet period. (Powlson, Jenkinson, Pruden and Johnston)

TABLE 5

Recovery of ^{15}N-labelled fertilizer by winter wheat at Rothamsted receiving near to optimum rates of N fertilizer

Experiment	Year and winter wheat variety	^{15}N labelled fertilizer applied kg N ha^{-1}	Date of N application	Rainfall in 4 weeks following N application (mm)	Grain yield (t ha^{-1} at 85% DM)	Recovery of fertilizer N, % In crop	In crop and soil (0–23 cm)
Multifactorial	1980 (Hustler)	194	4 March	92	8·89	53·8	69·6
	1981 (Hustler)	114	20 March	46	9·10	68·6	87·1
	1982 (Avalon)	174	13 April	21	7·13	83·6	92·2
Broadbalk	1980 (Flanders)	141	16 April	11	6·56	67·0	83·9
	1981 (Flanders)	147	14 April	69	6·33	50·8	70·5
	1982 (Flanders)	143	16 April	21	5·15	67·6	88·0

Uptake of fertilizer N by old grassland. In 1980, ^{15}N labelled fertilizer was applied to two plots on the Park Grass Continuous Hay Experiment, at the same rate as normal.

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In 1981 the plots reverted to the usual additions of unlabelled fertilizer. The total uptake of N in both cuts of grass from the plot receiving NH_4-N in 1980 was 145 kg. Of this, 36% came from fertilizer applied in the same year and 64% from non-labelled N already in the soil.

Two years after addition of the ^{15}N in 1980 about 60% of the labelled N had been removed in the crop and a further 30% remained in the soil and roots, whether the addition was as NO_3-N or NH_4-N (Table 6). In grassland, N is immobilized fairly soon after its application and takes many years to be remineralized. (Jenkinson, Johnston, Powlson and Pruden)

TABLE 6

Fate of ^{15}N labelled fertilizer applied to old grassland

	Fertilizer treatment				
	Unmanured since 1856	$(NH_4)_2SO_4$ annually since 1856		$NaNO_3$ annually since 1856	
	kg N ha^{-1}				
Labelled fertilizer application, April 1980	—	93·7		93·7	
	Unlabelled	Unlabelled	Labelled from fertilizer	Unlabelled	Labelled from fertilizer
In 1st cut 1980	22·1	54·6	48·0	52·0	43·8
In 2nd cut 1980	25·8	37·7	4·7	53·5	5·6
In 1st cut 1981	25·2	89·7	2·3	89·3	1·9
In 2nd cut 1981	36·3	37·2	0·8	35·7	0·7
Nitrogen in soil (0–50 cm), March 1982	8700	10 400	23·7	8400	28·3
In roots (0–50 cm), March 1982	80	130	5·2	50	1·9
Overall recovery of fertilizer N, %	—	—	90·4	—	87·7

Nitrification inhibitors

Mineralization of dicyandiamide-nitrogen. Dicyandiamide (DCD) contains 67% nitrogen by weight, and it may thus act both as a nitrification inhibitor and as a nitrogen fertilizer. Laboratory tests using ^{15}N labelled DCD suggest that DCD hydrolysis is slow since, at most, 5% of the DCD-N was present as NH_4- and NO_3-N after aerobic incubation of soil for 1 month at 30°C.

In a field experiment to determine the uptake of DCD-N by a crop, labelled DCD (20 kg ha^{-1}) was broadcast on winter wheat at Woburn in November 1981. In July, 16% of the applied DCD-N was found in wheat given no spring fertilizer N and 20% when 70 kg N ha^{-1} was given. Although DCD is a nitrogen source for crops, its contribution to their nutrition will always be small because of the small amounts required to inhibit nitrification ($<$20 kg ha^{-1}) and its slow decomposition in soil. (Rodgers)

Nitrification inhibitors with aqueous urea for grassland. Inhibitors injected with urea in 1979–80 increased dry matter production of, and nitrogen uptake by, a ryegrass ley (*Rothamsted Report for 1980*, Part 1, 248). Potassium and phosphorus uptakes by herbage harvested in 1980 were determined because alteration of the NH_4:NO_3 ratio in soils by nitrification inhibitors may affect P and K uptake. Inhibitors (nitrapyrin or sodium trithiocarbonate) injected with urea in November, January or March had little effect on K uptake by grass compared with urea only, as small decreases in per cent K contents

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were offset by increased yields. Inhibitors injected in November or January, but not in March, increased P uptake by 8–14%. This increase was due to an increase in both dry matter production and the proportion of P in the grass.

In 1980–81 preliminary tests of three inhibitors were made, combined with injected aqueous urea (375 kg N ha^{-1}) for a ryegrass ley. The inhibitors used were etridiazole, dicyandiamide or a CS_2-producing mixture (sodium trithiocarbonate plus potassium ethyl xanthate). When injected in November or January etridiazole or the CS_2-producing mixture, but not dicyandiamide, increased dry matter yields by 5–14% compared to urea injected without an inhibitor. All three inhibitors increased apparent percentage uptakes of fertilizer nitrogen by 6–20%. When injected in April no inhibitor had any significant effect on either yields or nitrogen recoveries. Etridiazole or a CS_2-producing mixture may, like nitrapyrin which has been tested previously, be suitable inhibitors for autumn or winter injection with aqueous urea. (Rodgers, Widdowson and Penny)

Investigations on phosphorus and potassium

Phosphorus-nitrogen interactions. Recently we have grown winter wheat with different amounts of N on soils containing a wide range, 2 to 45 mg kg^{-1}, of bicarbonate-soluble P to ascertain if the response of high yielding varieties to nitrogen is limited by the level of soluble P in soil. Fertilizer N was given on a single date in April at 40, 80, 120, 160 kg ha^{-1} for wheat grown as a fourth (1978, cv. Maris Huntsman) or sixth (1979, cv. Maris Huntsman, 1980, cv. Hustler) cereal and at 80, 120, 160, 200 kg ha^{-1} for Hustler grown in 1981 and 1982 as a first cereal after a 1-year break of winter beans. In addition 62·5 kg N had been broadcast on all crops at drilling the previous autumn. Grain yields varied over the range 2·7 to 11·2 t ha^{-1} according to season, variety, N applied and soil P.

The response to soluble P was modelled by an asymptotic regression equation with an additional trend:

$$\text{yield} = a - be^{-k\ (\text{soil P})} + c\ (\text{soil P})$$

where a is the asymptote without trend, b is a range parameter, k quantifies the rate of change in the curvature of the model with changing soil P and c is the trend. The same equation fitted the results from plots where P was last applied during 1973–76, or where soluble P was applied regularly.

The pattern of response was generally similar in all five years though maximum yields ranged from 7·4 to 11·2 t ha^{-1} grain. The same shape of P response curve fitted at each N rate, and there was no interaction between applied fertilizer N and soluble-P in soil. Above 15 mg P kg^{-1} the response to soil P was effectively linear and grain yield increased at 0·25 t ha^{-1} for each additional 10 mg P kg^{-1}. There was no significant difference in this trend between years or between N rates. (Johnston, Poulton, with Lane, Statistics Department)

Release of non-exchangeable potassium

Calibration of the calcium resin method. The calcium resin method for assessing reserves of K in soil has been calibrated against offtake of K by, and yield of, spring barley, winter wheat, field beans and sugar beet. Data were obtained from long-term experiments at Rothamsted, Woburn, Saxmundham, ADAS Experimental Husbandry Farms, and the Büntehof Agricultural Research Station, Federal Republic of Germany. Initially, plots receiving only N and P fertilizer were considered because on these only the lack of K should be limiting crop growth, and the crops would thus be exerting maximum stress on soil K.

Correlations were always better between quantities determined using resin and K

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offtake than between those quantities and yield. The quantities most important in predicting K offtake were the amount (M_1^∞) and rate of release (R_1) of exchangeable K, and the rate of release of fixed, or non-exchangeable K (R_2). Generally, the larger the demand of the crop for K, the more significant was R_2.

A multiple regression of M_1^∞, R_1 and R_2 gave a closer correlation with offtake than did exchangeable K as determined by standard methods with ammonium acetate. The difference was greater for those crops with a large demand for K, presumably because of their greater utilization of 'fixed' K. When NPK and FYM plots were included, the same multiple regression of resin quantities gave a good correlation with offtake, but only for the cereal crops. Ammonium acetate-exchangeable K gave no useful correlations. This suggests that the calcium resin method predicts the effect of fertilizer residues on K release better than a simple exchangeable K value. (Goulding)

Comparison of methods for assessing soil K reserves. Although the calcium resin method predicted the offtake of K by crops well in the tests described above, it is a long and complex procedure. It has therefore been compared with Haylock and MacLean's boiling nitric acid procedures, Electroultrafiltration (EUF), and a new acid extraction procedure in which the soil is leached with hot 20% HCl under reflux in a modified Soxhlet extractor. The practical advantages of the last method over other acid extractions are that concentrated HCl is a much safer material than concentrated HNO_3, and the soil is held in an extraction thimble separating it from the bulk of the acid, which obviates the difficulties of filtration and allows precise timing of the reaction. The methods were compared for their assessment of the K release characteristics of soils from three plots of the Broadbalk Experiment, and two plots of the Rotation I Experiment at Saxmundham. All the methods reflected the differences in K content of the soils which would be expected on the basis of mineralogy and history. The three acid extraction procedures gave slightly better correlations with exchangeable and non-exchangeable K balances than did EUF or the resin method. As predictors of K offtake by, and yield of, winter wheat, the resin method was poor, EUF better but the acid extractants best.

Overall, the HCl reflux method was the most satisfactory because it gave the best correlations with offtake and yield, and also measured the rate of K release, which EUF and Haylock and MacLean's methods do not. In view of our earlier experience with the resin method, its poor performance in this test is surprising. Tests of the HCl reflux method will be done on a broader range of soils. (Singh and Goulding)

Concentrations of potassium and nitrogen in spring barley. Investigations into the growth and nutrient content of spring barley (*Rothamsted Report for 1981*, Part 1, 258) have continued. For crops receiving adequate K, grown in four experiments in 1980 and 1981, there was a positive correlation ($r=0{\cdot}728$, $P<0{\cdot}001$) between maximum %K in the shoot dry matter and grain yield at harvest. Maximum %K in dry matter, which occurred just before the start of stem elongation, could only be definitely identified by frequent sampling. When K concentrations were recalculated on the basis of tissue water there was no relationship between K concentrations and grain yield, and all crops receiving adequate K maintained concentrations of about 200 mmol K kg^{-1} tissue water. Although the time-dependent changes in % dry matter and %K in dry matter were highly correlated ($r=0{\cdot}973$), there was no overall relationship between maximum % dry matter and grain yield. In contrast, spring barley grown on a soil which had received no K since 1852 had of only 50–70 mmol K kg^{-1} tissue water, but in all crops the concentration of K in the tissue water remained fairly constant with time. Hence deficiencies in K could be detected as reductions below 200 mmol kg^{-1} tissue water, irrespective of the growth stage.

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Total nitrogen concentrations expressed on a tissue water basis were similar in both adequately and inadequately N-fertilized crops, even though N concentrations in the dry matter were different. However, the differences in N supply resulted in different growth rates and grain yields. This suggests that N concentrations in the tissue water are closely maintained, at the expense of growth, and explains why growth is so sensitive to N supply. (Leigh and Johnston)

Water relations of wheat root cells. The miniaturized pressure probe (*Rothamsted Report for 1981*, Part 1, 262) has been used to measure turgor, hydraulic conductivity, and volumetric elastic modulus on cortical, hairless epidermal, and root hair cells of wheat roots.

Mean turgor pressures of 6·8, 5·5 and 4·4 bar were recorded in the cortical, hairless epidermal and root hair cells, respectively. The differences between the cortical cells and the other two cells types were statistically significant. Hydraulic conductivity was similar in the three cell types, so root hair cells are not specially adapted for water transport. Any special role these cells play in water transport must be related to their large surface area, not to properties of their membranes. The volumetric elastic modulus ranged from 10 to 150 bar in all cell types. Part of this variation arose because the modulus depended on cell volume, but in the same way in all three cell types. This volume-dependency may indicate that smaller cells have a greater capacity for turgor-driven growth. (Jones and Leigh, with Drs D. Tomos and R. G. Wyn Jones, U.C.N.W., Bangor)

Soil organic matter and biomass

Survival of soil biomass after air-drying of soil. Biomass C measurements were made on five moist soils (2 arable, 2 grassland, 1 woodland). After a 7-day preincubation, subsamples of all soils were air-dried at 25°C, and two of the soils were also air-dried at 10°C.

Biomass C contents of the soils air-dried at 25°C and rewetted, ranged from 49–68% of those in fresh soil (mean $56 \pm 8\%$). In the two soils air-dried at 10°C, biomass C was 90 and 103% of that measured in fresh soil. Biomass C in soils air-dried at 25°C, followed by 10 days preincubation at 40% water holding capacity ranged from 69–102% of that in fresh soil (mean $81 \pm 13\%$), and 92 and 98% of that in fresh soil for the two soils air-dried at 10°C.

These results show that although biomass measurements obtained from air-dried soil must be treated with caution, a considerable amount of biomass can survive air-drying, particularly at low temperatures. Rewetting of the air-dried soil, followed by preincubation before analysis, also permits restoration of the soil biomass, in some soils to near its original level. (Shen Shan-min, Brookes and Jenkinson)

Micronutrients and heavy metals

Effects of sewage sludge

Metal toxicity to plants due to past sewage sludge applications. The long-term effects of metals added in sewage sludge applied to the Woburn Market Garden Experiment are being investigated. Sludge was applied from 1942 to 1961 at rates supplying a total of 383 or 766 t dry solids ha^{-1}, and the total amounts of metals added have been calculated. These were approximately two or four times the Department of the Environment (1977) sludge disposal guideline limits for both Zn and Cu addition over 30 years, and one and two times that for Ni. The site offers a unique opportunity to study the long-term effects of sludge-derived metals in a field experiment, and old soil and crop samples

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taken between 1960 and 1981, and samples taken in 1982 are being analysed. The amounts of metals extractable from the soils by 0·05 M EDTA decreased during the first 10 years, but more recently appear to have remained constant at about 50% of the original extractable amount. The rates of decrease in extractability, and the current extractability as a proportion of the original, were the same for Zn, Cu, Ni, Pb and Cd. Relatively little of the added metals appear to have moved out of the plough layer. The decline in extractability of the metals was therefore not due to leaching, but must be due predominantly to changes in their chemical combinations in the surface soil. (McGrath)

Plant availability of zinc, copper, and nickel in sewage sludge. The variation in availability and phytotoxicity of Zn, Cu, and Ni in sewage sludge is being studied in a long-term experiment. The sludges used had been produced by adding Zn, Cu, and Ni salts separately to raw sewage. Combinations of these three metal-loaded sludges and of the uncontaminated sludge were used to produce a range of metal contents, and were added to the soils at a constant ratio of dry sludge solids to soil. Four soils are being used within a continuous crop (clover), a rotation of red beet and spring barley, and fallow.

The percentage reduction of clover yield due to application of heavy metals was greatest on the Cottenham and Newport series sandy soils, less on the Icknield calcareous clay, and not significant on the Carswell series clay. Yield reductions are decreasing with time. Application of Zn-loaded and Ni-loaded sludges increased the respective metal concentrations in clover on all soils, but Cu contents were only affected by application of Cu-loaded sludge on the Cottenham soil.

The yield of red beet was more affected by metal addition than was that of clover, the relative difference between soil series being similar with both crops.

The metal concentrations in the soil solutions extracted from fallow plots are decreasing with time; Zn and Ni are present in the soil solution partly as free ions and partly in complexed forms, whilst Cu is present mainly in complexed forms. (Adams, McGrath and Sanders)

Solubility of the metals in sewage sludge and sludge treated soils. The effect of pH on the amount of Zn, Cu, and Ni released into solution from the metal-loaded sludges is being studied. When the pH decreased below 6·0 the release of Zn and Ni and the proportion of metal present as free ion increased sharply. The release of Cu varied little above pH 4·2, and little free ion was present. These changes in metal release could be reversed by increasing the pH. The metals in the control sludge behaved in a similar manner to those in the metal-loaded sludges, and the capacity of the control sludge to absorb Zn from solution was also dependent upon pH.

The variation of metal release with pH in Newport soil treated with sludge was generally similar to that for the corresponding sludge alone. However, with the Carswell soil the sharp increase in metal release occurred at about 1 pH unit lower than with the Newport soil. With both soils the proportion of free metal ion in solution increased as the total metal concentration in solution increased. It is hoped to explain the effects of the sludges on plant growth from these measurements. (Adams and Sanders)

Concentrations of micronutrients in soil solutions as a function of pH and phosphorus fertilization. Soil samples from the long-term experiments at Rothamsted (Batcombe series) and Woburn (Stackyard series) with pH values between 4 and 7·5 and bicarbonate-soluble phosphorus concentrations of between 8 and 35 mg kg^{-1} were incubated at a water content near field capacity. Mn, Zn, Cu and Ni were determined in the soil solutions, and the proportions present as the divalent ions assessed using an ion-exchange equilibrium technique. In this, the divalent ions of the micronutrients are absorbed on a cation

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exchange resin at equilibrium, while the complexed forms of the metals remain in the solution phase. Separation and analysis of the solution allows the amount of free ion to be calculated.

Total Mn, Zn and Ni concentrations decreased as the solution pH rose; the free ions were the predominant species at low pH, but complexed forms became more important as the pH rose. Cu concentrations decreased very slowly as pH increased and the proportion present as Cu^{2+} fell from *c.* 20% at pH 4 to <4% at pH 7·5; Cu concentrations were much smaller, and the proportions present as cupric ion much larger, than in solutions from other soils which contained more organic matter. The variation of divalent ion concentrations with pH suggests that concentrations are controlled by adsorption of hydroxylated species. Metal concentrations were not significantly affected by extractable P concentrations, and the extent of adsorption and desorption of Zn, Cu and Mn on to the soils, while very pH-dependent, was almost independent of soil P levels. (Sanders with El Kherbawy)

Trace element contents of different soil series. Total amounts of Pb, Zn, Cu, Ni, As and Mn and amounts of Pb, Zn, Cu and Ni extractable by standard NH_4 EDTA solution in 99 topsoil samples representing Evesham, Hamble, Cegin, Wick, Whimple, Newport, Hanslope, Highweek, Clifton and Denchworth series from England and Wales were determined by X-ray fluorescence methods. Mean total concentrations and (in parentheses) extractable concentrations are Pb 49 (13·39) mg kg^{-1} air dry soil, Zn 88 (5·46), Cu 34 (5·48), Ni 29 (1·32), As 20 and Mn 863. The ranges of extractable amounts in the different series all overlap; for the total contents, however, some series are clearly distinguishable for one or more elements.

Although extractable and total amounts are correlated at the 0·1% significance level for Pb, Zn, Cu and Ni over the entire group of soils, the correlations are not strong enough to be used for prediction of extractable from total amounts. However, when series are considered individually very large correlation coefficients between extractable and total amounts are found for Pb in Hamble, Wick, Newport and Highweek series, and for Cu in these series and also Clifton and Denchworth samples. These correlations are large enough to allow useful predictions to be made.

Total contents of all elements determined, except Pb, are significantly correlated with the proportions of <2 μm material determined by particle size analysis for the entire group of soils; the correlation for Ni is sufficiently strong, $r=0{\cdot}879$, to enable total Ni content to be predicted from the particle size data.

For some series geographic trends in total contents that can be attributed to geological factors are detectable. About 10% of the samples have total contents of one or more minor elements that appear to be anomalously large for the particular series they represent. About half of these can be attributed to pollution. (Brown)

Root-soil relations

Mycorrhizal infections

Soil pH and mycorrhizal fungi. The fungi which formed mycorrhizas with roots of spring oats (cv. Peniarth) grown on the Rothamsted and Woburn long-term liming experiments were investigated. On both sites roots at pH 4·2 were colonized almost exclusively by the 'fine' endophyte (*Rhizophagus* (*Glomus*) *tenuis*) but on the most alkaline plots (*c.* pH 7·0) endophytes with broad hyphae ('coarse' endophytes) predominated. There was a decrease in the ratio of fine to coarse endophytes with increasing pH at the intermediate pH levels. Numbers and species of spores of coarse endophyte (chiefly *Glomus caledonius*) varied little over the pH range 5·0 to 7·0, with generally lower numbers at Woburn, but no chlamydospores were found at pH <5·0 at either site.

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A pot experiment tested the effect of sudden change in soil pH on the inherent rate of spread and the plateau of infection (parameters S and n respectively of our infection model) in oat for infection by crude inocula extracted from sites of pH *c.* 5·5 and *c.* 7·5 respectively on the Rothamsted long-term experiment. The highest plateaux and S values were measured using soils at the same pH as those from which the inocula came, suggesting that the populations of mycorrhizal fungi were adapted to soil pH, either through their species composition and/or physiological differences in strains of single species. (Wang, Stribley and Tinker)

Modelling infection spread in developing root systems. The effects of dispersed and placed inoculum were compared in leeks grown in tall containers, where growth was unrestricted and where root age could be assessed, and the spread of mycorrhizal infection along single roots could be observed. In a single root, the rates of increase in length of infected root (L_i) and of total root (L_t) were approximately linear. However, the logistic model (*Rothamsted Report for 1981*, Part 1, 252) for the spread of infection in the whole root system also described spread in a single root well, and fitted better than the linear model, especially during the early phase of infection.

Dispersed inoculum caused infection to be distributed throughout the root system in many separate individual lengths. By contrast, inoculum placed under the transplanted seedling, resulted in long, continuous infections extending from the root bases towards the root apices. Dispersed inoculum gave rise to many more 'fronts' of spread, but surprisingly the rates of increase of L_i were similar for both inoculation techniques. The observed pattern of individual infections agrees well with the assumption that spread rate of an infection front in a root is inversely proportional to the number of 'fronts' in that root. This simple model will be tested in axenic culture by direct observation, because it suggests an over-riding control mechanism of the plant on the rate of fungal growth at the level of the individual root. (Buwalda, Stribley and Tinker)

Mechanisms which determine the 'efficiency' of different endophytes. Different endophytes benefit their hosts to different extents, but the mechanisms which contribute to these differences in 'efficiency' are not understood. Differences in spore germination rate, infection potential, speed of spread of infection through roots, amount of external mycelium, or the physiological efficiency of the fungus in P uptake and translocation could be implicated. This has now been tested in experiments with four endophytes, one being a Californian isolate of *Glomus fasciculatus* which is very inefficient. Considerable differences in inoculum potential have been found, and consequently in rate of spread of infection, but much chemical and mathematical analysis remains to be done. (Menge, Snellgrove, Stribley and Tinker)

Mycorrhizal infection and uptake of anions. We investigated further the increased uptake of bromide by mycorrhizal cereals in the field (*Rothamsted Report for 1981*, Part 1, 261). The effect was confirmed in a pot experiment with spring wheat, where mycorrhizal infection increased bromide and chloride concentrations in root and shoot tissue. Consistently, the sum of the major anion concentrations (ΣA) in shoot tissue of cereals from four field experiments was increased strongly by mycorrhizal infection, but not by P additions, whereas the sum of the concentration of major cations (ΣC) was generally reduced by P but not altered by mycorrhizal infection. Hence P and mycorrhizal infection both reduced the cation excess (ΣC–ΣA), but by different mechanisms.

Since these common anions are mobile in soil and the increase in their fluxes to mycorrhizal roots were very large, it seems unlikely that the increased uptake was a result of simple absorption and translocation by mycorrhizal hyphae. We propose that

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the C drain in mycorrhizal roots (Snellgrove *et al.*, *New Phytologist* (1982) **92,** 75–87) may restrict the production of organic acids which regulate cellular pH, hence infected plants instead take up more anions to balance the cation excess and thus maintain internal pH. There are indications from recent work elsewhere that similar effects may occur following infections by ectomycorrhizal fungi and by take-all. (Buwalda, Stribley and Tinker)

Effects of mycorrhizas on cereal growth in the field. The work on responses of cereals to mycorrhizal infection in the field (*Rothamsted Report for 1981*, Part 1, 261) continued with an experiment on spring wheat and spring barley, and one on winter wheat and winter barley. These tested methyl bromide fumigation, inoculation with *Glomus mosseae* and addition of P (60 kg ha^{-1}).

TABLE 7

Percentage increases in yield of grain in response to (a) inoculation; (b) phosphorus on uninoculated plots in 1982

		Fumigated (kg P ha^{-1})		Non-fumigated (kg P ha^{-1})	
		0	60	0	60
(a)	Spring wheat	46	19	21	3 NS
	Spring barley	38	25	37	16
	Winter wheat	39	21	11	10
	Winter barley	39	17	21	9 NS
(b)	Spring wheat	78		59	
	Spring barley	53		102	
	Winter wheat	31		14	
	Winter barley	90		29	

NS: non-significant difference; all others are significant at $P<0{\cdot}05$ or better

The responses of spring wheat to infection were similar to those found earlier. Table 7 shows that all crops responded similarly to infection on fumigated plots, and that, unexpectedly, responses were still large on plots with high P. The responses to inoculation were always smaller on non-fumigated plots, but even on those with high P they were still significant for spring barley and winter wheat. No consistent differences in responses between spring and winter cereals could be found. The response to inoculation was generally, but not strictly, related to the response to phosphorus.

The rate of increase of percentage infection was much faster in the spring cereals, but when spread was related to thermal time (Gallagher, J. N. (1976) *The Growth of Cereals in Relation to Weather* Ph.D. thesis, University of Nottingham, School of Agriculture), using a base temperature of 5°C, rather than to chronological time, rates of spread were similar for all crops, suggesting that temperature is the principal variable controlling mycorrhizal infection.

Residual effects of inoculation on growth of direct-drilled cereals (*Rothamsted Report or 1981*, Part 1, 261) did not persist for more than 1 year. On fumigated plots invasion by natural inoculum was probably the cause, and on non-fumigated plots the general increase in inoculum density following continuous cropping with cereals presumably reduced the effect of added inoculum.

The general conclusions from our series of field experiments on mycorrhizas in cereals are: (i) yields of grain can be increased by artificial inoculation of plants on soils of low inoculum density, over a wide range of added P levels (up to 25% increase in soil with

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28 mg $NaHCO_3$-soluble P kg^{-1}); (ii) responses to inoculation are inversely related to the extent of development of natural mycorrhizas in root systems; (iii) there were no marked or consistent differences between wheat and barley, or autumn and spring sowings; (iv) we conclude that natural mycorrhizal infection is important for uptake of P by cereals in the field, though these crops do not depend wholly upon mycorrhizas as some species do. (Buwalda, Stribley and Tinker)

Aluminium tolerance of cereals. Sorghum and maize genotypes taken from the EMBRAPA Germplasm Bank, Sete Lagoas, Brazil, had been classified into high and low yield potential groups (HYP and LYP), based on the dry matter yields. Each group contained an Al-tolerant and an Al-sensitive genotype based on grain yield measurements in Brazilian field trials. These were grown in a controlled environment on an acid soil, pH 4·6, from Hoosfield Exhaustion Land. Up to 2 *mM* Al were given in water daily, the water content of the soil being kept at about one-third water-holding capacity.

Leaf and stem yields in early growth showed that the plants most tolerant to applied Al were the 'HYP-tolerant' and 'LYP-sensitive' genotypes. Thus, selections for Al-tolerance based on grain yields in the field are at variance with those in early growth in controlled environments. The Al concentration in the whole plant in early growth was greater in the HYP genotypes than in the LYP genotypes, and was not related to Al-tolerance in the field. Most of the Al was accumulated in the roots and any translocation was restricted to the stems, suggesting that the latter regulated the Al-tolerance mechanism.

Preliminary measurements with the X-ray fluorescence microprobe of the scanning electron microscope on the primary roots of maize showed that the Al treatments greatly increased Al, Mg and Si concentrations in the cortex. The Al and Si concentrations in the sensitive genotype increased much more with the Al treatment than in the tolerant cultivar. (Pitta and Talibudeen)

Soil and clay structure

Interaction of water with soils and clays. Our investigations of links between the swell-shrink behaviour of soils, and the clay minerals they contain, has continued with the measurement of water desorption-sorption isotherms of the clay fractions of soils, using a wide range of clay minerals in the mixed-layer group and three size fractions. Water sorption measurements on these fractions of the clays have been completed. The results for clays from soils formed on the Fullers Earth (Evesham series, ST 764815) and the Kimmeridge (Denchworth SE 725843) formations have been analysed in detail to distinguish the isotherm components arising from microporosity (including interlamellar water), multilayer formation on external surfaces, and capillary condensation of water in the interstices.

All isotherms showed irreversible hysteresis with the adsorption branch consistently representing less total sorption than the initial desorption branch. This hysteresis is attributed to an 'ageing' of the clay surface as the compressive stresses of drying bring planar surfaces of clay particles so close that they prevent free development of multilayers of water during the subsequent adsorption. There is an increase in microporosity and a decrease in external surface during the initial drying. In general the smaller size fractions have the larger total surface, but differences in mineralogy compound the effect of particle size on water sorption.

Changes in interlamellar volume influence the shape of adsorption isotherms, particularly at high relative pressures, and to some extent arise from changes in the interlamellar structure. These changes are being investigated in mixed layer clays of the

Fullers Earth clay in the first instance, using the diffractometer modified to control humidity.

The smectite, Ca-Redhill montmorillonite, studied first has a nearly regular 19 Å basal spacing that changes over a narrow humidity range ($1 < p/p_0 < 0{\cdot}90$) to a new phase with nearly regular basal spacing of 16 Å. As the humidity is further decreased to 0·33, the basal spacing of this structure decreases linearly with p/p_0 to about 15 Å and further decrease of the relative humidity changes the structure again to one which predominantly has a single water sheet between the layers.

By assuming that similar changes occur in the hydrated layers of the Fullers Earth clay it is possible to account for most of the features of the diffraction profiles. The first and strongest reflection in the profiles is an exception, however. The spacing migrates from 19·6 Å in the wet state to 18·4 Å at $p/p_0 = 0{\cdot}975$, to 17 Å at 0·92 in the state where the interlayer distance should be 16 Å, and to 14·7 Å at 0·33. The first reflection therefore is indicating an even greater range of basal spacing than occurs in Ca-Redhill montmorillonite, so that the position of this reflection cannot be used to indicate the structure of mixed-layer clays. One of the immediate tasks is therefore to calculate the diffraction profiles expected for the intermediate hydration states of smectite layers mixed with various proportions and types of ordering of mica layers. (Ormerod and Newman)

Regeneration of soil structure. Research into the regeneration of porous structure after the soil has been seriously compacted by traffic has continued. The first experiment, carried out on the Rothamsted farm, showed that trafficking and subsequent regeneration of structure was accompanied by measurable changes in bulk density, the size distribution and the orientation of coarse pores, but not in the mercury intrusion characteristics.

The soil at Rothamsted, Batcombe series, is well known for its ability to recover its structure after damage, and other kinds of soil with different reputations are now being compared. One of these is Hamble series, the other Evesham series, and we have experiments on these at Writtle, Essex, and Silsoe, Bedfordshire, respectively.

In all three soils traffic caused compaction and loss of air-filled ($> 60\ \mu m$) pore space, especially on Hamble series. All soils recovered some porosity in the summer, but least on the Evesham series. Compaction appeared not to have altered pores less than 60 μm across in any of the soils, which only alter in accordance with the soil moisture content. (Newman, with Bullock and Thomasson, Soil Survey)

Solute movement in soil

Simulation of the leaching of adsorbed organic compounds and chloride-36. A modification of the basic leaching model described above has been used to simulate the leaching and degradation of aldoxycarb, which is the weakly-adsorbed breakdown product of the nematicide aldicarb, and fluometuron, a more strongly adsorbed herbicide, in a fallow soil of the Denchworth series during winter. The basic anion leaching model was used to simulate the leaching of $^{36}Cl^-$ applied at the same time. The models predicted the overall patterns of movement of all three solutes and gave simulations at least as good as those from the more complex model of Leistra (*Agriculture and Environment* (1977) **3,** 325–335). (Addiscott, with Nicholls, Insecticides Department, and Bromilow, C.L.U.)

Spatial analysis of soil properties

Soil structure as a case of spatial variation. A long-standing problem in soil science is the measurement of soil structure. Pore geometry gives a good insight into structure, and developments in soil micromorphology and image analysis by computer can now provide

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much quantitative information from plane sections. We are attempting to apply stereological principles to infer the three-dimensional properties of the soil structure from such two-dimensional information. Certain properties of the pore geometry are readily estimated from random two-dimensional sections, e.g. pore volume from the cross-sectional area, and surface area from perimeter length. The extension of the two-dimensional information into three dimensions is being investigated by recording pore patterns on numerous close-spaced parallel sections and comparing them serially. Disconnected pore networks have been traced from section to section and their connectivity thereby estimated in the three dimensions. Estimates of the number of such networks were the same regardless of the spacing between sections, but the estimated connectivity per unit volume decreased as the spacing increased. This apparent anomaly is being investigated further. (Webster and Scott)

Spatial variation in leaching of solutes. The studies on the spatial variation of soil nitrogen (*Rothamsted Report for 1981*, Part 1, 266) have continued. The variation in concentrations of total and nitrate nitrogen, soil moisture, and, for comparison, also that of chloride from rain, were measured to give an insight into the spatial variation of leaching processes. The variation is defined by its overall magnitude and by the way in which it is distributed spatially on the ground. In autumn the nitrate in the topsoil appears to be related to both chloride and rate of mineralization, as measured by the amount of nitrate released over a 2 week period, but no such clear associations were found in spring. Moisture, chloride and total nitrogen contents of the soil vary more in spring than in autumn, although the spatial dependence of these properties is the same at both samplings. The fact that moisture content, total N and chloride (which the soil receives uniformly in rainfall) vary in the same way at both sampling times validates the experimental procedure.

Unlike the moisture content, the variation in the rate at which water drains from the sample holes is about twice as great in autumn as in spring. The spatial dependence of the variation also changes. Many of these seasonal changes may be attributed to the fact that the soil is dry in autumn, so that rate of wetting as well as drainage is being measured at this sampling.

Ammonia concentrations vary more in spring than autumn, but with the same pattern of spatial dependence. In contrast, nitrate varies to the same extent at both seasons but changes spatially between the two samplings. In autumn over 95% of the variance in nitrate occurs within 4 m^2, whereas in spring it extends to 64 m^2. A practical consequence of this is that a given number of cores provides more precise estimates of the nitrate content of the soil in spring than it does in autumn. (Whitmore, Addiscott, Webster and Thomas)

An experiment was also carried out to assess the value of spatial analysis in understanding the effects of leaching on vertical distribution of ions. Nitrate and chloride were applied as the sodium salts to the soil surface and leached by applications of water. Measurements of soil water content and the concentrations of NO_3, Cl and Na in soil water were made in 50 mm sections to 1 m at six points, at the end of infiltration and after redistribution. Semi-variograms calculated from these measurements often showed strong continuity for the three added ions. There was more variation at short lags after infiltration than there was after redistribution. Covering the soil with a polythene sheet during the redistribution phase increased the variation at short lags. (Kirda, Thomas, Addiscott and Webster)

Regional variation. The study of co-regionalization on particle-size fractions in the soil at Woburn was completed. The silt and sand fractions in the soil were strongly inter-

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dependent spatially with a common anisotropy in both topsoil and subsoil. This allowed the topsoil silt content to be estimated and mapped by co-kriging more precisely than by kriging from data on topsoil silt alone. Somewhat surprisingly the clay contents were related only weakly to sand and silt, usually because the absolute levels were so small. Using these results a general strategy was developed for estimating soil properties that are expensive to measure from a knowledge of their co-regionalization with others that can be measured cheaply. Both types of properties must be measured at some sampling points, but at others records only of the latter are needed. The estimation variances were worked out for several sampling ratios and a range of spacings on regular grids. The gains in precision from co-kriging at Woburn were modest, and the differences in cost of measuring particle size fractions at different depths is too small to justify a multiple sampling strategy. Nevertheless, there are other instances in soil research where large differences in costs exist, and where a co-kriging strategy would be of advantage. (Webster and McBratney)

Measurements of topsoil properties deriving from a survey of Zhangwu in north-east China were analysed geostatistically, to test the method on data from a large region. The contents of organic matter, nitrogen, phosphorus and sand all showed spatial dependence at this scale, though with large nugget variances. Soil pH was strongly autocorrelated. The kriged map of pH showed very clearly a zone of alkaline soil in the Liu river valley. Sampling was somewhat sparse, and the errors of estimation large therefore. Maps of the estimation variance showed where further sampling is needed to improve confidence, and that for pH a sampling interval of 1·3 km on a square grid would provide acceptable estimates for a survey of this region. (Webster and Xu)

Pedological studies

Palaeoargillic horizons. Buried interglacial palaeosols from eight well-dated sites in south-east England are being studied to assess variability in type and degree of pedogenesis within each interglacial stage; this should clarify the status and subdivision of the Palaeoargillic Sub-groups recognized in the system of soil classification currently used by the Soil Survey of England and Wales. At least one fine- and one coarse-textured profile dating from the Ipswichian and Hoxnian Stages, and three profiles from the pre-Anglian Valley Farm Soil have been described and sampled.

Preliminary results show that the Valley Farm Soil formed in sand and gravel containing little weatherable material. It is more strongly rubified than any of the Hoxnian or Ipswichian profiles, and its B horizons are strongly clay enriched. There is already evidence for distinguishing Valley Farm profiles occurring at different heights in the proto-Thames valley on the bases of rubification and clay illuviation. The different heights probably indicate terraces formed in separate pre-Anglian cold periods, suggesting that the Valley Farm Soil is composite, and contains evidence for pedogenesis during two or more pre-Anglian interglacials. (Kemp and Catt, with Bullock, Soil Survey)

Soil profiles influenced by man

Man-made urban soils. 'Dark earth' is a uniform black, man-made soil, 30 to >100 cm thick, which overlies Roman deposits in numerous, widely separated urban centres, including Canterbury, Colchester, and the City of London, and seems to date from the 3rd–8th centuries A.D. Samples from 17 sites are being studied to discover its exact origin and the reasons for its colour and widespread urban distribution. The occurrence of bone and shell fragments, large amounts of total phosphorus, and artifacts suggest that the material is partly an accumulation of domestic refuse, but particle size analyses of fractions <2 mm and preliminary mineralogical studies show that it is

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composed mainly of inorganic soil or sediment. However, at many of the sites this soil/sediment component differs from the natural underlying deposit, which though containing the same amount of clay, has a wider range of sand and silt contours. Other deposits have also been analysed from most of the sites, and compared with these the dark earth has much smaller ranges of clay, silt and sand contents; most dark earth samples are sandy loams or sandy silt loams. (Catt and Farrington)

Deposition and soil development at Stoke Newington. Samples from an archaeological excavation at Stoke Newington (north London) were analysed to help date deposits of a tributary of the river Lea, which contained Palaeolithic and Mesolithic artifacts. The brickearth contained the characteristic silt mineral assemblage of Devensian loess, and a typical gleyed Flandrian soil profile had developed in the overlying clayey alluvium. Thin sections of samples taken from the junction of the brickearth and alluvium showed a heterogeneous microfabric with blocks of clay (probably London clay), which must have been geliflucted from clay outcrops higher up the tributary valley. The surface of the stream gravels beneath the brickearth was deeply channelled, indicating that the gravels were deposited shortly before the brickearth was laid down. These observations allowed us to reconstruct a history of deposition on the site, starting with gravel aggradation and then loess sedimentation during the Late Devensian cold period, and proceeding without any hiatus to accumulation of fine early Flandrian alluvium. (Catt, with P. L. Gibbard, Botany School, Cambridge University, and P. Harding, Inner London Archaeological Unit)

Soils developed in loess. We continued to study the mineralogical composition, age and weathering of loess, which is a very widespread soil-forming material in England and Wales. Its properties determine natural soil characteristics important to crop growth, such as available water content or the tendency to slake and form a hard capping, and determination of its age in many profiles is useful in dating soil forming processes.

Profile development in Hamble series. This soil series in thick loesss or brickearth is usually classified as an argillic brown earth, but some profiles have field characteristics suggesting pre-Devensian pedogenesis. The fine sand and coarse silt fractions from successive horizons in one such profile on the Taplow Terrace of the Thames near Heathrow airport were studied to determine the age of the loess and weathering changes in it. Some depletion of apatite, glauconite and chlorite could be attributed to weathering in the top 70 cm. However, some features of the mineral suites suggested that upper horizons of the profile had developed in Devensian loess and the lower (Bt) horizons in brickearth containing only pre-Devensian loess. Thin sections of the Bt horizons showed that most of the 5% illuvial clay, which originally formed void argillans, had been incorporated into the soil matrix by deep frost disturbance. This also suggests that the loess of these horizons was deposited before the deep frost disturbance during the Late Devensian. A longer pedogenic history of this type also explains why the Bt horizons are slightly redder (6YR 5/6) and better structured than is usual in Hamble profiles on Late Devensian loess. (Catt)

Other brickearths in the Thames Valley. The coarse silt fractions of another ten unweathered brickearth samples from various sites in the middle Thames valley were analysed mineralogically in an attempt to date them by comparison with loesses of known ages elsewhere. Principal coordinates analysis of the non-opaque heavy mineral data showed that, as expected, some samples were like Late Devensian loess, but others showed greater resemblance to older (Wolstonian and Anglian) loesses. As all the latter

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samples contained more sand than typical aeolian loess, and some also had more clay, they had probably formed by fluvial or other reworking of older loesses. The mineralogical comparisons therefore date the main loess deposits from which the brickearths were derived, and provide only a maximum age for deposition of the brickearths. Before using the composition of loess to help date soil-forming processes, it is therefore important to decide whether it has been reworked in such ways or not. (Catt, with P. Gibbard, Botany School, Cambridge University)

Weathering in podzols developed in Late Devensian coversands. Humoferric podzols developed in windblown coversands deposited 10–11 thousand years ago at the end of the Late Devensian cold period are common in parts of Norfolk, Lincolnshire, Yorkshire and Lancashire, and are useful for studying acid pedochemical weathering of sand minerals. Mineralogical studies of five unburied podzols representing the main English coversand areas provided the following sequence of resistance to weathering: apatite (least resistant) $\ll$ brown hornblende, tremolite/actinolite $<$ augite, hypersthene/bronzite, green hornblende $\ll$ epidotes $<$ garnets $\ll$ other minerals. The less resistant types (before epidote in this sequence) were completely removed from the Ea horizons and strongly depleted in the Bh and Bs horizons of the more weathered profiles. The weathering sequence deduced from this work was used to interpret microscopic etch features on garnet, hornblende and augite grains. Variations in intensity of weathering between the profiles could not be related to differences in climate, soil texture or bulk chemical composition of the original sands, and may result from differences in vegetation cover at various times over the last 10 000 years. (Catt and Bateman)

Leaf protein extraction

In a conventional screw-expeller, a narrow-angle cone rotates inside a perforated cylinder. By inverting this principle, and rotating a disc against a perforated wide-angle cone, a more efficient unit for pressing juice from leaf pulp has been made. It works satisfactorily, but was finished too late in the season for thorough testing. Preliminary tests suggest a throughput of 500 kg h^{-1} for a unit 0·8 m in diameter, but much larger units could be made. A pulper suitable for feeding this press has been made but not yet tested.

Work continues on various factors (e.g. leaf species, time of harvest, technique of protein separation, antioxidants) which influence the reactivity of β-carotene in moist leaf protein preserved with salt. (Pirie)

Analytical and Isotopes Sections. One hundred and forty-three thousand analyses were done this year, 36·9% more than last year; of the total, 8·7% was done for other departments. (Brown, Cosimini, Fernhead, Messer, Pope and Thompson)

The Inductivity Coupled Plasma Emission Spectrometer (I.C.P.) instrument, installed in November 1981, was brought into routine use from April 1982. Comparison of results obtained from the I.C.P. instrument for P, K, Ca, Mg and Na in our normal range of samples with those obtained by colorimetric and atomic absorption techniques, gave linear correlations of better than 0·99 and slopes of one. Similar figures were obtained for Cu and Zn.

Determinations of P in crop samples are now all done using the I.C.P. The I.C.P. instrument has facilitated analytical work involving a number of trace elements and phytotoxic heavy metals, which is now taking up an increasing proportion of our time. (Cosimini and Pope)

Eight thousand seven hundred analyses of radioactive isotopes were done this year, 2% fewer than the average of the previous 5 years; 52·6% of the total were done for other departments. (Smith)

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Staff and visiting workers

G. E. G. Mattingly retired in March after 31 years at Rothamsted, all spent in this Department. He was Acting Head in 1976 and Organizational SPSO 1978–1982. E. C. Ormerod retired in May after 17 years and Kathleen Branson resigned after 8 years. T. M. Adams was appointed in February, M. L. Fearnhead in January and J. L. Doran and Miss Lisa Nicholls both in December.

N. W. Pirie went to Calcutta for the Golden Jubilee of the Indian Statistical Institute, and gave keynote talks at the Frontiers of Research in Agriculture symposium and at the International Conference on Leaf Protein Research in Aurangabad. He also visited Bangalore and Coimbatore to see the work on leaf protein. G. W. Cooke visited the International Fertilizer Development Centre at Muscle Shoals, Alabama, in March and October, to advise on research programmes. He attended the 12th Congress of the International Potash Institute at Goslar (Federal Republic of Germany) in June and was joint author of a paper presented there. In April he gave a course of lectures in Madrid. P. B. Tinker and J. A. Catt presented papers at the 12th International Congress of Soil Science in New Delhi in February, and P. B. Tinker visited Paris in April to serve on an International Jury for the World Phosphate Rock Institute Agronomic Award. He presented papers at the VI Simposia Sobre O Cerrado in Brazil and at the Reclamation of Disturbed Land Symposium at Logan, Utah, both in October. T. M. Addiscott gave a paper at a Nitrogen Research Workshop in Leuven, Belgium, in January, and participated in project evaluations at the Swedish Agricultural University in December. A. C. D. Newman attended an EEC Workshop on Soil Structure Methodology in Brussels in April, and P. B. Barraclough visited the Royal Veterinary and Agricultural University, Copenhagen, to study their modelling methods. A. E. Johnston visited Brazil in October to give a paper at a colloquium on soil organic matter at CENA, University of Sao Paulo, and then went to IAPAR, Londrina, Parana State, to discuss collaboration on soil organic matter work. R. J. Darby attended the Second International Summer School in Agriculture, on cereal production, in Dublin in July.

R. Harrison was awarded a Ph.D. by Birmingham University and Karen S. Eide a Ph.D. by London University. J. G. Buwalda, P. B. S. Hart, G. V. E. Pitta, G. J. T. Scott (CASE student) and Gamin M. Wang continued their studies, R. Kemp (NERC-CASE research student with Birkbeck College) arrived as a Ph.D. student, and H. Jones (SERC-CASE research student with UCNW, Bangor) spent 4 months here. R. M. Bateman was awarded a CNAA B.Sc. degree 'with commendation' for his day-release studies.

Dr J. Hartmann arrived from Switzerland in February for 1 year as a Royal Society—Swiss National Foundation Exchange Research Fellow to work on drought stress effects on ion uptake, and Miss Orpah Farrington of the Museum of London arrived in July to study the 'dark earth' found on old urban centres. Professor J. A. Menge returned to the USA after spending 9 months sabbatical here, and Mr F. Annot returned to the Netherlands, Dr Elgal El Aggory to Egypt, Mr Shen Shan-min to China, Dr K. D. Singh to India, Dr C. Kirda to Turkey, Mr Maneewon Methee to Thailand and Dr M. I. El-Kherbawy to Egypt, having completed varying periods here.

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Book

1 Cooke, G. W. (1982) *Fertlizing for Maximum Yield.* Third edition. London: Granada, i–xiv, pp. 1–465.

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SOILS AND PLANT NUTRITION DEPARTMENT

Theses

2 Eide, K. S. (1982) *Some aspects of pedogenesis and vegetation history in relation to archaeological sites in the New Forest.* Ph.D. Thesis, University of London.

3 Harrison, R. (1982) *A study of some montmorillonite-organic complexes.* Ph.D. Thesis, University of Birmingham.

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4 Brookes, P. C., Jenkinson, D. S., Powlson, D. S. & Tate, K. R. (1982) The secret life of the soil. *New Scientist* **96,** 564.

5 Cooke, G. W. (1982) An introduction to soil analysis. *World Crops*, January/February, 8–9.

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