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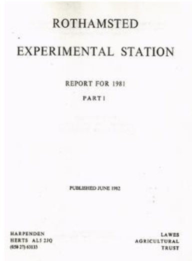
Report for 1981 - Part 1


ROTHAMSTED

EXPERIMENTAL STATION

REPORT FOR 1981

PART I

Soils and Plant Nutrition Department

P. B. Tinker

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Introduction

The Yield Variation programme continues to produce good results, with best yields of winter wheat in excess of 10 t grain ha^{-1} on most of our sites. Interesting relationships of crop growth with soil compacted layers were found at Maulden and at Woburn. This field programme is closely integrated with our development of a method for predicting nitrogen fertiliser requirement, which is tested on all these sites. The prediction, from the amount of mineral N in the profile in spring, has been successful in the last 2 years. The measurement of mineral N in this way is laborious and may not be practical in spring, so we are working on a computer simulation of this, based on the existing nitrate leaching model.

It is appropriate to stress here the extent to which modelling and mathematical methods are increasing in the Department. The modelling for the immediate aim of nitrogen prediction is mentioned above. In addition there is modelling of detailed flow processes in soil, and a major effort on the wheat crop growth model which is being developed as part of the Four-Institute Yield Variation programme. Work is starting on the modelling of the whole nitrogen cycle in soil, and we expect this to contribute to improving the prediction of N fertiliser need. New statistical methods of dealing with the overriding problem of soil heterogeneity are now being applied to several problems, including trace element distribution over long distances, nitrate distribution over much shorter distances, and the distribution of soil voids on a very fine scale.

Much work on nitrogen is reported here, of which the results obtained with ^{15}N are notable. We now have true recoveries of N fertiliser by winter wheat, both in the year of cropping and the following year. The work with grass/clover swards has given quite exceptional nitrogen fixation values, in the region of 400 kg N ha^{-1} year^{-1}.

Work on root–soil relations is developing more rapidly. Data on the inflows of ions into wheat roots in the field are being accumulated, and show particularly how these are linked to the growth rate of the whole crop. This raises questions of how the root inflow is controlled by the state of the whole plant, which will now receive attention. Studies on plant composition in barley are showing that the concentrations of nutrients in the water phase during development are controlled very closely. Plant composition is also important in relation to our studies on vesicular–arbuscular mycorrhizas. Carbon transfer from leek shoots into roots has been shown to be greater, when plants are mycorrhizal, but a lower leaf percentage dry matter appears to compensate for this in terms of the growth of the whole plant.

Measurement of thermal changes with a microcalorimeter during cation exchange on clays have given a better insight into the exact nature of exchange sites, and together with measurements of the free energy of exchange, allow different types of exchange sites to be identified. It is considered that these represent different clay minerals, so that small percentages of different mixed or interlayered clay types can be detected.

The work on subsoil modification continues. No striking yield responses were detected in the wet summer of 1981, which is not surprising if the cause of yield improvement is an enhanced supply of water. However, penetrometer measurements have shown that there are still significant decreases in subsoil mechanical resistance several years after its cultivation.

During the year a new programme on toxic metals in sewage sludge was started, funded by the Ministry of Agriculture, Fisheries and Food (MAFF). This project aims to understand in basic terms the chemistry of the heavy metals in sludges, and from this to define more clearly their phytotoxicity.

Work on trace elements in general will be greatly aided by the acquisition of an ARL inductively coupled plasma optical emission spectrophotometer, which allows simultaneous analysis of up to 25 elements. This will also facilitate our routine analyses for cations and phosphorus. With our existing atomic absorption and X-ray fluorescence facilities, we are now well equipped for elemental analysis. A new scintillation counter for isotope work was provided, which is also valuable for measurement of ATP in the soil biomass. During the year a start was made to the much needed upgrading of some of our old laboratories.

Yield variation

This year was again very successful in terms of the yields achieved, with 10 t ha^{-1} grain or more on five of the six sites on which we work. Most notably, a very high yield was obtained on the light sandy soil at Woburn. It may be that high yields can be obtained on all soil types without clearly identifiable problems, so long as the agronomic treatments and weather are appropriate. However, it is clear that high yields are much more easily and frequently obtained on some soil series than on others, as is also emphasised by results in the 'Ten-Tonne Club' survey. This is important, because an underlying question in the Yield Variation programme has always been whether some soils have inherent limitations to yield. The large body of data obtained on these very high-yielding crops will be exceptionally useful in testing the wheat crop simulation model, which has now reached the stage of being run as a single unit.

A very interesting comparison appeared this year, in that both at Woburn and at Maulden there was evidence of a compact soil pan at shallow depth, but the Woburn experiment produced the largest yield we have ever had on these light soils, whereas the Maulden experiment yielded least of all the sites. This emphasises the need to be able to predict when a soil pan will be damaging to yield, which is not yet possible.

Field experimentation. The Rothamsted multifactorial winter wheat experiment in which eight two-level factors were tested in all combinations (Multidisciplinary Activities p. 19) was the basis of comparison for five other winter wheat experiments. To allow direct comparison between the growth, nutrient and water requirements and final yield of wheat on contrasting soils six of the eight factors tested at Rothamsted were tested on light sandy loam at Woburn (Cottenham series). Fungicide and aphicide were also tested at Rothamsted, but were given basally at Woburn. Hustler wheat was sown on 15 September or on 30 October at Rothamsted and on the days following these at Woburn, using the same seed source, seed rate (375 seeds m^{-2}) and seed drill. Thereafter all operations on the two experiments, i.e. soil and crop sampling, N applications and herbicide, fungicide and aphicide sprays were made alike and on consecutive days. Irrigation was given whenever the soil moisture deficit exceeded 25 mm (Multidisciplinary Activities pp. 20 and 25).

Less complex experiments were repeated in 1981 at Saxmundham, and on the same private farms used in 1980. Each experiment tested a combined treatment of fungicides and systemic insecticides, with none and four levels of nitrogen fertiliser, applied either singly or as a divided dressing (on two varieties at Saxmundham). The rates of nitrogen applied to the experiments were chosen to give top yield at the third level of N, based on the previous cropping and soil analysis for mineral N. The varieties used were Avalon (2nd wheat) sown 10 October 1980 at Billington, Hustler (10th wheat) sown 7 October 1980 at Maulden, Norman (1st wheat) sown 1 October 1980 at Hexton and Avalon and Virtue (1st wheat) sown 29 September 1980 at Saxmundham.

Many data are yet to be processed, but some of the main results are given below.

Yield and dry matter. Results of the Rothamsted and Woburn trials are in the Multidisciplinary Activities section, p. 26, but some yield data are given here for comparison (Table 1). Dry matter accumulation at Hexton and Billington showed exponential growth from early March to anthesis in mid-June, when the growth rate became linear at Billington, but declined at Hexton. Dry matter was maximal at the beginning of August, when Hexton had accumulated 18·2 t ha^{-1} and Billington 15·3 t ha^{-1}.

TABLE 1

Yield of grain at 85% DM t ha^{-1}. Both Rothamsted and Woburn data are for plots receiving aphicide and fungicide sprays

Treatment	Experimental site					
	Hexton		Billington		Maulden	
Aphicide/fungicide N (kg ha^{-1})	None	Sprayed	None	Sprayed	None	Sprayed
Nil	7·94	8·19	4·50	4·86	3·88	5·26
60	9·62	10·57				
90	10·30	10·87			6·84	7·60
120	10·11	11·06	8·68	9·15	6·94	7·99
150	10·46	11·23	8·70	9·45	7·54	8·33
180			8·72	9·98	7·14	8·02
210			8·48	9·83		

	Saxmundham	
Aphicide/fungicide N (kg ha^{-1})	None	Sprayed
Nil	6·70	6·59
80	8·15	9·43
120	8·51	10·24
160	8·69	10·63
200	8·51	10·91

	Rothamsted		Woburn	
Sowing date N (kg ha^{-1})	15/9	30/10	16/9	31/10
	Not irrigated			
80	9·45	8·95	—	—
150	9·52	9·21	9·09	7·05
220	—	—	8·98	7·89
	Irrigated			
80	9·27	8·69	—	—
150	9·14	8·75	9·73	7·85
220	—	—	9·79	8·56

The pattern of dry matter accumulation at Maulden was quite different, very possibly because of the presence of a soil pan at 28 cm depth, discovered by hand augering and penetrometer measurements, which may have impeded both drainage and root penetration. Dry matter accumulation remained linear from early March to mid-May, when exponential growth began. This delay in the onset of the exponential growth phase resulted in the Maulden crop having accumulated less than half the dry matter at anthesis (7·3 t ha^{-1}) compared with 15·3 t ha^{-1} at Hexton. However, the exponential growth phase was maintained beyond anthesis to give a maximum of 14·0 t ha^{-1} in early August. It appears that a delay in the establishment of exponential growth prevents the achievement of large yields. Dividing the N dressing had no effect, so means of divided and single dressings are given in Table 1. Grain yields from these experiments were proportional to the amount of dry matter accumulated. The best combination of treatments produced 11·41 t ha^{-1} at Hexton, 10·91 t ha^{-1} (mean of two varieties) at Saxmundham, 10·16 t ha^{-1} at Billington and 8·60 t ha^{-1} at Maulden.

The pesticide sprays gave reasonable control of foliar diseases (assessed by Prew, Plant Pathology Department) and on average prevented the loss of between 0·75 and 1·50 t grain ha^{-1} (Table 1).

At Billington, Maulden and Saxmundham, 220, 276 and 250 plants m^{-2} were established, but at Hexton a low seed rate gave only 206 plants. However, the crop successfully compensated for this loss and by anthesis ear numbers had stabilised at 435, 462, 403 and 501 at Billington, Maulden, Hexton and Saxmundham respectively. (Widdowson, Darby, Penny and Hewitt)

SOILS AND PLANT NUTRITION DEPARTMENT

Soils. The Woburn site was on Cottenham series, and there was clear evidence of a compact layer at 35 cm depth, with bulk densities up to 1·7 g cm^{-3}. The Rothamsted site was on Batcombe series, as usual. In order to vary the preceding crops, the fields used for the outside experiments were changed from 1980. At Billington the new site was on old arable land, on Evesham series soil developed in Gault Clay head about 1 m deep over Gault Clay. At Hexton in a valley bottom site the soil was a sandy variant of the Halton series with head of very calcareous clay passing to calcareous gravel at 0·4 m depth over Chalk Marl at 1 m. At Maulden the soil was Hanslope series in Chalky Boulder Clay, but with poorer drainage than at the other sites and elsewhere on Hanslope series. This poor drainage and late, shallow extraction of water by crops (*see* below) was attributed to a cultivation pan, which gave maximum resistance to a soil penetrometer at a depth of 28 cm. (Darby and Weir)

Fungal diseases on outside sites. Mildew was present at Billington, Hexton and Maulden, but was always less than 1% area infected of the topmost leaf. Brown rust was also present in small amounts at Billington and Hexton. Yellow rust was prevalent and damaging at Maulden, infecting 11% flag leaf area of unsprayed plots by 5 August. *Septoria* was the commonest foliar pathogen and by the beginning of August the mean infected areas of flag leaves on unsprayed plots were Billington 4%, Hexton 1% and Maulden 7%. In the spring eyespot (E) and take-all (TA) were prevalent at Billington (E 37%, TA 58% plants infected) and Maulden (E 17%, TA 28%), where the crops followed cereals in 1980, but were absent at Hexton following a 2-year break.

The pesticide sprays gave reasonable control of all the foliar diseases and probably also of eyespot, so the large yield responses to these sprays at Billington and Maulden were expected. However, the almost equal response at Hexton was not expected in view of the much smaller amounts of diseases present. (Prew, Plant Pathology Department, with Darby)

NO_3-N in wheat stems and in soils. The NO_3-N content of the wheat stems was measured at fortnightly intervals from mid-March to mid-July. Concentrations in unfertilised wheat were approximately 800 ppm at Billington and Hexton in mid-March but only 400 ppm at Maulden. Nitrate concentrations, where no fertiliser was given, had declined to zero at Billington and Maulden by 24 April and by 8 May at Hexton. The application of fertiliser N increased nitrate concentrations in the stems, and these eventually declined to zero in mid-June at Maulden and Hexton but were maintained above 100 ppm until mid-July at Billington.

The changes in mineral N in the soils of these experiments are discussed in relation to the prediction of fertiliser need (p. 250). Broadly, the concentration of soil profile NO_3-N paralleled that in the wheat stems, as last year. (Widdowson, Darby and Williams)

Water use. Estimates of maximum transpiration (from W. Day, Physics Department) were combined with on-site rainfall measurements to calculate potential soil moisture deficits for each site. Small deficits of between 27 and 35 mm developed towards the end of April, and large deficits of between 102 and 126 mm in the 6 weeks to the end of July. Neutron moisture meter measurements showed that at Billington the maximum amount of water extracted was 10 mm less than the predicted deficit of 120 mm. Water was removed to a depth of 1·25 m, but 35% of this was from 0 to 25 cm and only 8% came from below 1 m. At Hexton the maximum amount extracted was 125 mm, equal to the predicted deficit. Water was removed from 1·5 m depth, 30% from 0 to 25 cm but again only 8% from below 1 m. At Maulden extraction matched potential deficit until 80 mm had been removed on 10 July. It then declined, in contrast to prediction which increased to

102 mm. Water was removed to depths of only 0·8–0·9 m, approximately 60% coming from the top 25 cm. The soil exploited by the roots of the Billington and Hexton crops thus supplied sufficient water to satisfy atmospheric demand, whereas the soil pan at Maulden probably caused shallower rooting, and led to droughting during the grain-filling period. On non-irrigated plots at Woburn virtually no water was extracted from below 90 cm depth, probably due to poor rooting caused by the compacted layer.

The deep subsoil thus appeared to supply relatively little of the water demand to wheat crops in this year, though some rooting probably occurred at these depths. A crop on Rothamsted sheltered from rain from anthesis onwards extracted water to 1·45 m, but even so only 22% came from below 1m. (Weir and Darby)

Root growth of winter wheat crops. Sowing date had a pronounced effect on root growth in the factorial experiments. By 17 March, only 9% of the final root system of the late-sown crop at Woburn had developed, compared with 34% for the early-sown crop. The roots and shoots of the early crop continued to grow faster to 24 June, the average root growth rate being 1·25 g DM m^{-2} day^{-1} compared with 1·02 g m^{-2} day^{-1} for the late-sown crop. By anthesis, the early-sown crop had 167·0 g m^{-2} of dry root (35·16 km m^{-2}), 73% of which was in the top 20 cm of soil, whilst the late-sown crop had 110·9 g m^{-2} of root (20·81 km m^{-2}), 65% of which was in the top 20 cm.

The pan at about 35 cm at Woburn affected the appearance and distribution of the roots, and samples from below 20 cm contained thick, kinked roots. Few roots were found below 40 cm until anthesis, but the total amount of root produced then was satisfactory, since an equivalent plot at Rothamsted contained only 104·8 g m^{-2} (32·45 km m^{-2}) root. Root lengths g^{-1} at Rothamsted were greater at all depths, indicating a greater degree of branching in the Rothamsted soil.

The shoot:root ratio (S/R) is of great importance in modelling the growth of plants, but very little information is available for field crops. S/R for the early crop at Woburn increased steadily from 1·0 in March to 7·0 by anthesis, whilst at Rothamsted S/R increased from 3·8 in March to 9·7 at anthesis. However, for later sown crops at Woburn the pattern was different, with an S/R value of 2·2 in March falling to 1·4 in April, before increasing to 8·4 at anthesis. N was not applied to the late crop until 21 April, and early N deficiency may have caused the majority of assimilate to be directed to root growth.

The slow shoot growth and nutrient uptake of the late crop in March and April gave low inflows (μg m^{-1} root day^{-1}) of 1·1 (N), 0·5 (P), 3·8 (K), 0·4 (Ca) and 0·1 (Mg). Following N application, inflows for April–May increased sharply to 32·2 (N), 2·7 (P), 23·0 (K), 2·3 (Ca) and 0·7 (Mg), which were similar to those found with the early crop during March–April. (Barraclough)

Winter wheat crop model. This model is being prepared in collaboration by four Agricultural Research Council supported institutes; Long Ashton, Letcombe Laboratory, Plant Breeding Institute and Rothamsted. It has been designed as a group of sub-models, of which those needed to describe the behaviour of a healthy crop not affected by water or nutrient shortage have been written as Fortran computer programs and are being tested for correct numerical operation. Sub-models to deal with the effects of water shortage or excess and nutrient deficiency will be added later. The model for the healthy crop is in three main sections, which deal with the timing of phenological events, the vegetative development (tillering leaf and root growth) and the production and partitioning of assimilate to various plant parts, particularly to grain.

In the phenological development model the growth stages of the crop (emergence, double ridge, anthesis and maturity) are reached after the passage of set totals of thermal time. This time, in degree days, is the daily integral of temperatures above 1 °C, except that after anthesis the base is increased to 9°C. A period of low temperature vernalisation is allowed for by a factor modifying thermal time. Between emergence and double ridge the effect of short days in slowing development is allowed for by another factor. This sub-model is similar to that reported by Gallagher, Taylor and Thorne (*Rothamsted Report for 1980*, Part 1, 53).

The vegetative growth model simulates the growth of shoots, leaves and of roots. The initiation and growth of shoots and leaves depends on thermal time. The group of shoots produced in any week (a cohort) has a single pattern of leaf growth, but the chance of survival of shoots in each cohort depends on age.

The production of dry matter is based on a model leaf canopy in which the light is reduced to 66% after passing one leaf-area layer. The leaf photosynthesis process follows a non-rectangular hyperbolic relationship of net photosynthate to incident light intensity, and allowance is made for reduced photosynthesis when there is much light but temperature is low.

The root model deals with the growth of seminal or lateral roots only. Growth is limited by the amount of assimilate available and a maximum seminal root extension rate. Lateral roots are distributed so that their weight and length decrease exponentially with depth.

Partitioning of assimilate in a first very simple model is by subdivision to roots, leaves, stems and ears, the proportions changing with the development stage of the crop. The proportions are based upon published data and measurements made on Hustler wheat and the factorial experiments at Rothamsted and Woburn.

Output from these sub-models has been tested against data from some of our field experiments. Though there are some discrepancies, results are promising, and we will now link all the sub-models needed for unrestricted growth together, and compare them with data from plots of factorial experiments where the growth is thought to be little restricted. (Rayner and Weir, with Dr J. R. Porter (Long Ashton Research Station) and Dr P. L. Bragg (Letcombe Laboratory))

Effect of soil type on 1980 yields of winter wheat. Soil series were identified for 634 fields in the ICI Ten-Tonne Club Survey for 1980 (made available by Mr J. D. Hollies of ICI Ltd). Yields of wheat ranged from 11·7 to 3·6 t ha^{-1}, with a mean of 7·3 t ha^{-1}, 0·4 t ha^{-1} greater than that of the equivalent 1979 survey (*Rothamsted Report for 1980*, Part 1, 247).

Yields of 10 t ha^{-1} or more were achieved at 36 sites, 21 more than in 1979, in soils of 21 different soil series, seven of which were common to the 2 years. These very large yields were achieved on five sites on soils of Chalky Boulder Clay (Ragdale and Hanslope Series) and at four sites each on Andover series in loess over Chalk, and Beccles series in loamy drift over Chalky Boulder Clay. As in 1979, loess was present in a larger proportion, 39%, of soils producing these high yielding crops than in those of the survey as a whole, 28%. A difference between the 2 years was that in 1980 36% of these soils had clayey textures, compared with only 13% in 1979.

The soils of the whole survey could be grouped into 92 soil series, but of these only 21 were represented by more than ten sites each. In a few instances the series could be used to indicate potential crop yield. Thus yields from the 15 sites of Park Gate series ranged 10·3–7·6, mean 9·1 t ha^{-1}, whereas those from the 13 Dunkeswick sites ranged 7·3–4·7, mean 6·1 t ha^{-1}. Clearly it was much easier to obtain large yields on Park Gate than on Dunkeswick series soils in 1980. However, for most series the range is much larger, e.g. Andover series, mean 6·1 t ha^{-1}, had four sites yielding more than 10 t ha^{-1} and five less than 5 t ha^{-1}, so describing a site as on Andover series would give no indication of yield potential.

Pelosols (8·0 t ha^{-1}) and Ground-water gley soils (7·8 t ha^{-1}) gave mean yields well above that of the population mean, Brown soils (7·3 t ha^{-1}) equal to it and Lithomorphic soils and Surface-water gley soils (7·0 t ha^{-1}) below the mean. This range, 8·0–7·0 t ha^{-1}, is larger than that observed in 1979, and the yields from the slowly permeable, clayey Pelosols were 1·3 t ha^{-1} larger than in 1979. Within this major group the Argillic Pelosols gave a mean yield of 8·3 t ha^{-1}: this is 2·7 t ha^{-1} larger than the mean of the same group in 1979. Soils of clayey texture, including Pelosols, gave a mean yield of 7·2 t ha^{-1}, an increase of 0·8 t ha^{-1} on 1979. It was thus easier to obtain large yields of winter wheat on clay-rich soils in 1980 than 1979. An explanation for the difference in yields of clayey soils may lie in an interaction of weather with soil type, which is being sought by comparing the spatial distributions of sites to regional weather differences in 1979 and 1980. (Catt, Rayner and Weir)

Investigation on nitrogen

Nitrogen requirement prediction. The control of the use of nitrogen is at present not accurate. The results of our yield variation work suggest that very high yields can be obtained on most soils, but that accurate control of rates and times of inputs may be important. A better method of controlling N rate is very desirable, for yield, profit and the avoidance of nitrate pollution. This section deals with an integrated study of the mineral nitrogen level under wheat crops in relation to final yield, and a method for predicting soil mineral nitrogen levels in a practical way. The results so far are promising, though no method can be perfect when the weather in the summer is unpredictable and the final yield only a target, at the time in spring when decisions about rates have to be made.

Nitrogen in soils under wheat during winter and spring. Soils on all six experiments in the Yield Variation group (see p. 245) were sampled to 90 cm at crop emergence in autumn, and at least twice in spring, to measure NH_4-N and NO_3-N at 30-cm intervals. In the Rothamsted and Woburn experiments wheat was sown on two dates, and so samples were taken under each on five occasions. Much rain fell after the first sowing and by 26 November most of the NO_3-N had been leached from the sandy Woburn soil (Table 2). Samples taken there in early December to 220 cm depth showed much NO_3-N in the 100–160 cm horizons, with 82 kg NO_3-N ha^{-1} in the 100–200 cm layer, compared to 57 kg ha^{-1} between 0 and 100 cm. At Woburn, the effect of sowing date on soil NO_3-N content was small, probably because crop uptake was much less important than leaching in diminishing the NO_3-N concentration.

TABLE 2

Effect of rainfall and crop on soil NO_3-N (to 90 cm) under winter wheat, following potatoes, at Rothamsted and Woburn, 1981

	NO_3-N (kg ha^{-1})					Inter sampling rainfall (mm)			
Date of sampling	3 Oct.	26 Nov.	3 Feb.	16 Mar.	22 April	3 Oct.–26 Nov.	–3 Feb.	–16 Mar.	–22 Apr.
Rothamsted									
Wheat sown									
15 September	160	98	40	13	1	134	92	91	49
30 October		124	152	102	13				
Woburn									
Wheat sown									
16 September	132	23	14	3	4	127	69	73	49
31 October		38	24	6	6				

At Rothamsted leaching was much less important, and little NO_3-N was lost by 26 November. Afterwards NO_3-N declined steadily with time under the September-sown wheat, in all three 30-cm layers. This must have been due mostly to crop uptake, because under the later sowing NO_3-N declined only in the 0–30 cm horizon, remained constant in the 30–60 cm and increased greatly in the 60–90 cm horizon. After 2 February NO_3-N diminished in all three layers under the late crop so that differences in soil N content caused by sowing date diminished from 111 kg N ha^{-1} on 2 February to 12 kg ha^{-1} on 22 April.

The clay soils at the four off-station sites were sampled once at emergence in autumn, and twice in spring. The wheat at Saxmundham and Hexton followed legumes and their soils contained 135 and 191 kg NO_3-N ha^{-1} respectively late in October. The wheat at Billington and Maulden followed long runs of cereals, and their soils contained 73 and 86 kg NO_3-N ha^{-1} respectively at the same time. In March NO_3-N in the 0–30 cm horizon had declined in all four soils, had changed little between 30 and 60 cm, but had increased in the 60–90 cm horizon. Afterwards NO_3-N declined rapidly at all three depths, so that by mid-April none remained from 0–60 cm, and only a little from 60–90 cm at the two sites which followed legumes.

In autumn, NH_3-N ranged from 8 kg ha^{-1} at Woburn to 46 kg ha^{-1} at Maulden, with intermediate values elsewhere. Amounts tended to increase until early February but had declined by mid-April.

The overall pattern is thus clear. Both leaching losses and crop uptake contribute greatly to decrease of mineral N in the soil profile, with the latter process dominant if the crop is early sown and grows well on a heavy soil. Clearly this is a major reason for sowing early. The increase in NO_3-N at 60–90 cm implies that it also increases at even greater depths, as was certainly true in the light soil at Woburn. The problem of the recovery of this deep NO_3-N is a matter of great interest, and parallels exactly that of the recovery of water below 1 m in the profile (pp. 247–248). (Widdowson, Darby and Bird)

The prediction of nitrogen fertiliser rates from mineral N in the soil in spring. The Balance Sheet approach for N manuring proposed by Remy and Hebert (*Comptes Rendus des Seances de l' Academie d'Agriculture de France* (1977) **63,** 700–714) in France and widely tested there, involves the definition of supply of N by soil and demand by crop. We have attempted to adapt this to our conditions, using amounts of NO_3- and NH_4-N found under wheat in February, with some data derived in France. The objective was to provide sufficient N for grain yields of 10 t ha^{-1} of a feed wheat. Growth curves showed that at Rothamsted N uptakes of 180 kg ha^{-1} were associated with yields of this order, less than the amount found in France. We have adopted a compromise value of 25 kg N taken up per tonne of grain, and this is used with the original standard values in the equation of Remy and Hebert.

This method has been applied to the six Yield Variation sites in 1980 and 1981, and has given good results in all cases, achieving the aim of having the peak of the N response curve between rate 3 and rate 4 (*see* p. 246 and *Rothamsted Report for 1980*, Part 1, 244). (Widdowson)

Prediction of nitrogen in the soil profile under winter wheat. Work has continued on the prediction system described in the *Rothamsted Report for 1980*, Part 1, 249. In addition to leaching, mineralisation and nitrification, uptake of N by the crop is now also calculated. The above-ground dry weight of the crop is computed from an equation of Greenwood *et al.* (*Annals of Botany* (1977), **41,** 987–997) with time replaced by degree-days of soil temperature. The %N in this dry weight is computed from another equation by Greenwood *et al.* (*Journal of the Science of Food and Agriculture* (1980), **31,** 1343–1353). No explicit attempt is made to model root system development. Instead the model designates a fraction of the soil in each layer from which the roots may extract nitrate, and this fraction decreases exponentially with depth and increases with the above-ground dry weight. When insufficient N is found available to meet the computed uptake increment, the dry weight increment is also decreased and a warning is printed out.

Ths system's ability to predict the amount of mineral nitrogen held in the profile and in the crop in early spring from mineral N measurements in September or October has been tested for 12 sets of data spread over five of the Yield Variation sites and 2 years. The regression of the total mineral N measured in the profile in early spring (N_T) on that simulated accounted for 92% of the variation in measured N_T. A more stringent test of the system was obtained by simulating the decline in N_T between autumn and spring. The regression of the measured decline on the simulated decline accounted for 88% of the variation in the measured decline, without making any allowance for denitrification. It thus appears possible to predict the mineral N in the soil in spring from soil and weather data, starting from the measured level in autumn. The possibility of finding easier alternatives than direct measurements in the whole profile in autumn is now being studied, e.g. measurement of mineral N in the top 50 cm only may prove adequate. (Addiscott)

Nitrification and urease inhibitors

Ammonia volatilisation losses from urea. Various techniques to improve the efficiency of urea as a fertiliser for ryegrass, by reducing NH_3 volatilisation losses, were tested on a ryegrass ley in White Horse II field, Rothamsted. In this experiment losses did not exceed 5% of the urea N applied.

Soil temperature had little effect on losses from a single 375 kg N ha^{-1} application of prilled urea broadcast in January 1981 (soil temperature 10 cm under grass *c.* 4°C) or April (*c.* 9°C). NH_3 losses over the 4 weeks after application were small, at 17 kg N ha^{-1}. Application of hydroquinone (5 kg ha^{-1}), a urease inhibitor, as a coating on urea prills reduced losses to 8 kg N ha^{-1}, although hydroquinone had little effect on the rate of urea hydrolysis. Calcium chloride (50 kg ha^{-1}) used as a coating on urea prills to complex any NH_3 formed by urea hydrolysis slightly reduced losses to 13 kg N ha^{-1}. No NH_3 volatilisation was detected when aqueous urea (375 kg N ha^{-1}) was band injected in January or April. Total volatilisation losses from divided broadcast dressings of urea in April, June and August were less than that from a single dressing broadcast in April. (Rodgers, Widdowson and Penny)

Test of winter N fertiliser and a nitrification inhibitor on winter wheat. The work at Woburn (p. 27) strongly suggests that N deficiency developed during winter. Eight additional early-sown plots were included in the Rothamsted and Woburn multifactorial winter wheat experiments. They were all given basal aldicarb, fungicides and aphicide and at Woburn irrigation also. They tested in factorial combination dicyandiamide (DCD) at 3 kg ha^{-1}, urea at 40 kg N ha^{-1} and application in December or February. Urea applied in December at Woburn more than doubled dry matter by 12 March, but had no visual effect at Rothamsted, and DCD had little effect on either soil. Early N had beneficial effects on dry weight, grain yield and N uptake at Woburn, but none on the N-rich Rothamsted soil (see p. 250), where it decreased grain yield. DCD had smaller though comparable effects to fertiliser N at Woburn but inconsistent effects at Rothamsted. (Widdowson and Ashworth, with Welbank, Botany Department)

SOILS AND PLANT NUTRITION DEPARTMENT

Work with ^{15}N

The interpretation of experiments with ^{15}N labelled fertilisers. Experiments with ^{15}N labelled fertilisers often show that the addition of fertiliser increases the uptake of soil N by the crop, which suggests a priming action. Such results can be artifacts; for example, if the soil immobilises N from a combined pool of fertiliser N and soil inorganic N, an 'apparent' priming action will be found of magnitude

$$i\,\Delta t F/(F+P+0{\cdot}5\,m\,\Delta t)$$

where i is immobilisation rate, m mineralisation rate, F the quantity of ^{15}N labelled fertiliser N added, P the quantity of inorganic N in the soil and Δt a short interval of time. Theoretical studies, including a literature review, are in progress on the interpretation of results from ^{15}N experiments. (Fox, Rayner and Jenkinson)

Residual fertiliser nitrogen and nitrogen mineralisation in Broadbalk soils. Last year we reported the crop uptake of ^{15}N labelled fertiliser applied on Broadbalk in 1980 and the total amounts of N derived from fertiliser in the soil at harvest (*Rothamsted Report for 1980*, Part 1, 247–248). We have now measured the proportions of this residual N that are in the inorganic fraction (ammonium + nitrate) and in the microbial biomass (Table 3).

TABLE 3

Inorganic nitrogen and biomass nitrogen (kg ha^{-1}) in Broadbalk soils at harvest 1980 derived from ^{15}N labelled fertiliser applied in spring

Labelled fertiliser N applied	Labelled fertiliser N remaining in soil (0–23 cm)	Inorganic N		Biomass N		N mineralised in 20 days at 25°C	
		Total	Derived from fertiliser	Total	Derived from fertiliser	Total	Derived from fertiliser
0	0	13·0	0	174	0	13·6	0
47·3	15·8	19·2	0·6	195	4·2	14·7	0·9
94·4	17·2	22·9	1·0	222	5·0	18·6	0·8
141·0	24·6	22·8	1·4	207	6·7	21·7	1·2
181·6	25·0	22·0	1·4	210	7·3	23·7	1·3

The soils contained up to 23 kg inorganic N ha^{-1} at harvest, but only about 1 kg ha^{-1} of this was derived from the labelled fertiliser applied in spring. The total amount of N held in the soil microbial biomass was measured as 200 kg N ha^{-1} (Table 3) by fumigating with $CHCl_3$, incubating for 10 days at 25°C, and measuring the extra N mineralised by the fumigated soil. Between 4 and 7 kg ha^{-1} of this biomass N was derived from the labelled fertiliser applied in spring. Although this is a small proportion of the total biomass N, it represents about 30% of the fertiliser-derived N in the soils. The remainder of the residual fertiliser-derived N (11–16 kg ha^{-1}) is in dead roots and other dead organic matter. Fertiliser-derived N represented 2–3% of the soil biomass N and up to 6% of the inorganic N present at harvest, but it was less than 1% of the total soil N.

Plots that had received N for many years contained more total biomass than the plot without N, had more ^{15}N in the biomass, and mineralised more N on incubation, presumably because of the larger crop residues in the fertilised plots. The faster mineralisation of N in soils with a long history of N fertiliser applications could account for the increased uptake of unlabelled soil N by wheat given increasing amounts of labelled fertiliser N, as was observed in the ^{15}N experiment on Broadbalk. This may be a real effect rather than one resulting from mineralisation-immobilisation turnover as described above. (Shen, Powlson, Pruden and Jenkinson)

The uptake by wheat of fertiliser N applied to the preceding crop. Some of the fertiliser N applied to a crop remains in the soil and stubble at harvest. If ^{15}N labelled fertiliser is used the availability of this soil and stubble N to the next crop can be measured. In 1980 equal amounts of ^{15}N labelled NO_3-N and NH_4-N were applied to microplots located on some of the main plots of the Broadbalk Continuous Wheat experiment (*Rothamsted Report for 1980*, Part 1, 247–248). In 1981 unlabelled N was applied at the same rate to these microplots and the uptake of ^{15}N by the crop measured (Table 4). Between 6 and 11% of the ^{15}N remaining in the stubble of the 1980 crop and in the top soil was recovered in the 1981 crop. This percentage recovery does not include the ^{15}N taken up by the roots or immobilised by the soil in the 1981 season. Assuming that the ratio (uptake of ^{15}N by the above ground parts of the plants)/(^{15}N remaining in the soil) was the same in 1980 and 1981, from 10 to 14% of the ^{15}N remaining in soil and stubble at harvest 1980 was mineralised and subsequently either taken up by the 1981 crop or re-immobilised. Little of the ^{15}N in the soil and stubble at the 1980 harvest was lost over winter, because between 87 and 96% of it was accounted for in crop and soil at the 1981 harvest. (Hart, Jenkinson, Johnston, Powlson and Pruden)

TABLE 4

Uptake of N (kg ha^{-1}) by winter wheat from fertiliser applied in the spring of the preceding year

Addition of ^{15}N labelled fertiliser in spring 1980	Labelled fertiliser N remaining in soil (0–23 cm) at harvest 1980	Labelled fertiliser N in stubble, at harvest 1980	Labelled fertiliser N in grain, straw, chaff and stubble of 1981 crop	Labelled fertiliser N remaining in soil (0–23 cm) at harvest 1981	Recovery of labelled fertiliser N remaining in soil and stubble at harvest 1980 in plant and soil at harvest 1981, (%)
47·3	15·8	0·8	1·0	15·0	96
94·4	17·2	1·6	2·1	15·8	95
141·0	24·6	2·4	2·6	21·0	87
181·6	25·0	3·8	2·6	22·7	88

Effect of husbandry treatments on grain N concentration of wheat. Using data obtained by Rothamsted staff over 20 years, it can be shown that protein concentration in grain of wheat is considerably influenced by husbandry treatments, especially by the amounts of fertiliser N (Benzian & Lane, *Journal of the Science of Food and Agriculture* (1981), **32,** 35–43). Grain N% was also affected by varying the timing of N applications, by N residues and by changing from an all-arable farming system to one including leys. The same set of experiments was examined for such effects. Differences in grain N%, which may appear small, can assume practical importance if values are close to the 'HGCA breadline' (2·14 %N in dry matter).

Grain N% of wheat grown as a first test crop was greatly affected by varying the crop sequence in a long-term rotation experiment at Rothamsted. Wheat following arable cropping did not reach bread-quality standard even with 150 kg N ha^{-1} of fertiliser N, but following lucerne, yield was larger and all N% values exceeded 2·14 %N. Wheat after grass leys yielded less than after arable and had only slightly more grain N%. However, when wheat was the second test crop, yield and N% increased in the order: arable sequence, grass ley with N, grass ley with clover, lucerne—indicating delayed mineralisation of nitrogen from the grass leys. (Benzian, with Lane, Statistics Department).

Responses of grass and grass–clover swards to nitrogen. Between 1978 and 1981 we cooperated in a joint ARC–ADAS series of experiments (GM 23) studying some of the factors limiting the yields of grass and clover grown singly and in combination. The experiments, on a silty clay loam at Rothamsted and a sandy loam at Woburn, tested selected combinations of the following: five mixtures of ryegrass and clover species and lucerne, two cutting frequencies, up to six rates of fertiliser N, times of applying N fertiliser, pathogen control and irrigation.

The plots were sown in spring 1977, for full cutting treatments in 1978. Yields were, on average, least in 1979 and most in 1980, and those for selected treatments from the six-cut regime, averaged over the 4 years, are in Table 5. At Rothamsted and Woburn yields of both ryegrass and grass+clover mixtures increased with fertiliser N up to 400 kg N ha^{-1}. Ryegrass yields were further increased by 600 kg N in the absence of irrigation at Woburn, and with irrigation at both sites. Yields were less at Woburn without irrigation, reflecting the lower water holding capacity of the lighter soil. Ryegrass+Blanca clover swards yielded more than ryegrass+S 100 swards in the absence of applied fertiliser N but with increasing dressings of fertiliser N, yields became more nearly the same.

TABLE 5

Yield and N uptakes 1978–80 by pure ryegrass and ryegrass+clover swards cut six times a year

Site and sward type	Without irrigation: N applied kg ha^{-1} 0	200	400	600	With irrigation: N applied kg ha^{-1} 0	200	400	600
			Yield, dry matter, t ha^{-1}					
Rothamsted								
Ryegrass only	1·5	7·5	11·6	11·0	2·0	7·8	13·4	13·9
Ryegrass+Blanca clover	8·9	10·5	11·8	—	10·3	11·5	12·2	—
Ryegrass+S 100 clover	7·7	9·6	11·4	—	9·6	11·6	13·3	—
Woburn								
Ryegrass only	0·8	5·9	9·7	11·3	1·4	6·5	13·0	14·3
Ryegrass+Blanca clover	8·1	9·6	10·9	—	11·8	11·3	12·3	—
Ryegrass+S 100 clover	5·7	7·7	10·4	—	10·7	11·5	13·0	—
			Nitrogen uptake, kg ha^{-1}					
Rothamsted								
Ryegrass only*	26	161	325	369	34	153	343	451
		(68)	(75)	(57)		(59)	(77)	(70)
Ryegrass+Blanca clover	349	377	416	—	384	404	433	—
Ryegrass+S 100 clover	279	306	392	—	378	369	443	—
Woburn								
Ryegrass only	11	140	283	368	28	134	304	422
		(65)	(68)	(60)		(53)	(69)	(66)
Ryegrass+Blanca clover	289	352	421	—	472	460	453	—
Ryegrass+S 100 clover	166	241	345	—	387	371	399	—

* Recoveries of N in brackets, as %

Large amounts of N were removed in herbage harvested from ryegrass+clover swards given no fertiliser N, suggesting that exceptionally large amounts of N were fixed by the clover. For ryegrass+Blanca the amounts ranged from 298 to 472 kg N ha^{-1} (yields were 7·8 and 11·8 t ha^{-1} respectively) and for ryegrass+S 100 clover the range was 166–387 kg N (yields 5·1–10·5 t ha^{-1}). Most extra N was taken up from the fertiliser applied to the grass+clover swards in the absence of irrigation but irrigation had little effect on apparent recovery of N by grass alone (difference in N uptake with and without fertiliser, as per cent of applied N). With the largest N applications recoveries by ryegrass were 55–75%, but unexpectedly, very poor recoveries (29–40%) were obtained from the smallest applications. These swards developed in old arable soils, and these poor recoveries may arise because some nitrogen was immobilised in soil organic matter, which would be expected to increase as the sward aged. This could be very important for manuring of grassland in largely arable farming systems, and further experiments are desirable. (Johnston and Poulton, with McEwen and Yeoman, Field Experiments Section)

Investigation on phosphorus and potassium

Characterisation of soil phosphorus by ^{31}P nuclear magnetic resonance spectroscopy. The value of ^{31}P nuclear magnetic resonance spectroscopy (^{31}P NMR) to characterise the forms of phosphorus in alkali extracts of soil has recently been demonstrated (Newman & Tate, *Communications in Soil Science and Plant Analysis* (1980), **11,** 835–842). We have applied this technique to four soils from long-term experiments at Rothamsted using the 400 MHz NMR spectrometer at Queen Mary College, London.

Ultrasonic dispersion with 0·5 M-sodium hydroxide extracted 35% of the total P from an old grassland soil (Park Grass plot 3d, no fertiliser, unlimed). The major classes of P compounds identified were inorganic orthophosphate (22% of the P in the extract), phosphate monoesters (48%) and phosphate diesters (14%). Pyrophosphate and phosphonate represented 4 and 3% respectively of the P extracted. The phosphate monoesters are thought to comprise mainly inositol phosphates while the diester region of the ^{31}P n.m.r. spectrum includes phospholipids and nucleic acids. Phosphonates, which are unusual among organic P compounds in that they contain a direct carbon-phosphorus bond, occur to only a limited extent in nature. The only previous identification of phosphonate in soil was in New Zealand tussock grasslands where they were thought to have accumulated from cells of a protozoon. The alkali extract of a Park Grass soil given phosphate fertiliser contained the same forms of P as the unfertilised soil and in roughly the same proportions, except for a much greater amount of inorganic orthophosphate and possibly a small amount of polyphosphate.

Old grassland soil from Highfield contained orthophosphate, monoester and diester P but no pyrophosphate or phosphonate. Measurement on Highfield soil that has been bare fallowed since 1960 showed that diester declined much more sharply than monoester during 21 years of bare fallow. This is consistent with a rapid decline of nucleic acid and phospholipids derived from microorganisms and plants but a slower decline of the more stable inositol phosphates. (Powlson and Tate, with Professor E. W. Randall, Queen Mary College, University of London)

Organic phosphorus changes in soils. Permanent grassland on Highfield, Rothamsted, was ploughed up in 1960 and the soil left fallow. Organic P in soil samples taken at intervals during the following 18 years was estimated, as previously (*Rothamsted Report for 1979*, Part 2, 41–61), in 1960, 1963, 1970, and 1978. Almost 18 kg organic P ha^{-1} year^{-1} was mineralised during the first 3 years after the grass was ploughed, and about 100 kg P ha^{-1} during the whole period. About 14 kg organic P ha^{-1} year mineralised on plots given a total of 568 t ha^{-1} of sewage sludge between 1942 and 1961 in the Woburn Market Garden experiment (Johnston & Wedderburn, *Rothamsted Report for 1974,* Part 2, 79–101).

Accumulation of organic P under long leys. Organic P contents and rates of accumulation of organic P under grass were measured on two plots with contrasted manuring from Rotation I at Saxmundham. After 70 years arable cropping, part of the experiment was sown with a mixture of timothy and meadow fescue in spring 1970.

Accumulation of organic P was at very similar rates on soils which had received PK fertiliser for the 70 years (5·6 kg P ha^{-1} year^{-1}) or farmyard manure (5·2). Similar measurements on a ley–arable experiment at Rothamsted showed an accumulation of 6–7 kg P ha^{-1} $year^{-1}$. In both cases the rates of accumulation are about one-quarter of the phosphate applied to the leys. (Chater and Mattingly)

Evaluation of phosphate reserves in soils. Soils from long-continued field experiments at Rothamsted, Woburn and Saxmundham were used in an experiment using ryegrass grown in a controlled-environment room to evaluate weighted mean L-values (labile P concentration in soil). The soils were chosen to represent a wide range of organic and manurial treatments. Under the experimental conditions used (small soil volume, weekly addition of all nutrients other than P) the initial amounts of $NaHCO_3$-soluble P in the soils accounted for more than 95% of the variance in plant-P uptake and weighted L-values. Analysis of parallelism showed these relationships were independent of soil type, location or manurial treatment in the field.

The most interesting result from the experiment was that *rate* of increase in L-values with time was linearly related to the initial $NaHCO_3$-soluble P, which thus provides information on the availability of initial non-isotopically exchangeable soil P reserves. Plants finally removed about 70% more P from soils than was present initially as $NaHCO_3$-soluble P and about one-half the labile soil P. (Brookes, Mattingly and Mitchell, with White, Statistics Department)

Release of non-exchangeable K. The method for assessing the reserves of K in soil by exchange with calcium resin (Talibudeen *et al.*, *Journal of Soil Science* (1978), **29**, 207–218) is being calibrated against the amounts of K removed by field crops to see how well the laboratory results can be used to predict the availability of potassium in the field. The Agricultural Development and Advisory Service kindly provided potassium offtake data for spring barley seven sites) and winter wheat (six sites) which have a low potassium requirement, and also for potatoes, mangolds and sugar beet with a high potassium requirement. Comparisons are also being made between long-term experimental plots that have received different amounts of potassium and fertilisers, to give different rates of potassium uptake or accumulation. (Goulding)

Enthalpies of exchange as a means of assessing clay mineral purity. Research on the enthalpies of K-Ca exchange on clays, using a microcalorimeter, has continued and shown that exchange enthalpies are characteristic of particular clay minerals. Very small amounts of impurities in clays, nominally of a single type, can thus be measured, which is very difficult by X-ray diffraction (XRD).

In smectites, groups of cation exchange sites with differential enthalpies of Ca→K exchange of between $-5{\cdot}2$ and $-7{\cdot}5$ kJ eq^{-1} were found to be characteristic of the exchange surfaces of fully expanding, 'true' montmorillonite. Sites with more negative enthalpies were characteristic of interstratified non-expanding and partially expanding micaceous layers. Using this technique to examine four widely recognised 'standard' smectites only a fine fraction ($<0{\cdot}2$ μm) from Wyoming seemed to be a 'true' montmorillonite as defined above.

Impurities of 2:1 layer minerals lessen the commercial value of kaolinites, and it is important to detect and measure them. Six kaolinites (from English Clays Lovering Pochin and Co. Ltd, St Austell, Cornwall) were examined by this technique. Four of the samples had been shown by XRD to contain from 3 to 15% of 2:1 layer minerals. Using characteristic enthalpy values, similar total amounts (2–11%) of 2:1 minerals were found, but the type and distribution of the impurities were different. The other two samples contained no 2:1 impurities detectable by XRD, but the microcalorimetric technique detected 1–1·5% vermiculitic, micaceous and smectitic layers. (Goulding and Talibudeen)

Growth and nutrient content of spring barley. Detailed studies of the growth and nutrient content of field-grown spring barley were made during 1980 and 1981. In 1981 samples were taken from 50 plots from three different experiments at Rothamsted and Woburn with a variety of treatments. Frequent sampling began at the three-leaf stage and continued until final harvest.

Tissue concentrations of N, P, K, Ca, Mg and Na, expressed as percentage in dry matter, showed the usual pattern of an initial rise followed by a decline during the rest of the growth period. However, nutrient contents expressed on the basis of fresh weight or as concentrations in the tissue water remained more or less constant, except when the crop was ripening rapidly. For instance, in the samples from the 1980 Hoosfield experiment K was maintained at a concentration of $8{\cdot}20 \pm 0{\cdot}13$ g kg^{-1} tissue water irrespective of the manurial treatment. The concentrations of nutrients in the shoot depended on the relationship between relative growth rate and rate of uptake of nutrients into the shoot. For N and K these rates were highly correlated ($r=0{\cdot}89$ and 0·95, respectively) demonstrating the close control over uptake exerted by the plant. (Leigh, Johnston and Branson)

Soil organic matter and biomass

Measurement of soil biomass phosphorus. The extra phosphate made extractable to 0·5 M-$NaHCO_3$ by fumigation with $CHCl_3$ can be used as a measure of the amount of phosphorus held in the soil microbial biomass (*Rothamsted Report for 1980*, Part 1, 253).

In seven of the eight soils so far studied, between 85 and 100% of the $CHCl_3$-released P is inorganic (P_i) after 24 h $CHCl_3$ fumigation. We now propose that soil biomass P can be estimated by the increase in extractable inorganic P alone, without serious error. In one soil, however, P_i was only 65% of the total '$CHCl_3$-released P'. Further soils are being analysed to see if this is an isolated case. The soil microbial biomass, measured in seven soils of different cropping history and manurial treatments, contained between 1·2 and 2·8% P (overall mean $2{\cdot}0 \pm 0{\cdot}6$%). (Brookes, Powlson and Jenkinson)

The adenylate energy charge of the soil microbial biomass. Soils contain a large microbial biomass, most of which is in a resting state. However, this mainly resting biomass has an ATP content of the same order as that of actively growing organisms (Jenkinson, Davidson & Powlson, *Soil Biology and Biochemistry* (1979), **11,** 521–527). Active cells have an adenylate energy charge (defined as AEC=(ATP+1/2 ADP)/(ATP+ADP+AMP) of about 0·9. Spores have an AEC much less than this, so that AEC can give an indication of the metabolic state of an organism.

We have now developed a method for measuring the AEC of the soil biomass. Portions of soil are dispersed ultrasonically with a solution of paraquat, trichloracetic acid and phosphate (Jenkinson & Oades, *Soil Biology and Biochemistry* (1979), **11,** 193–199) to extract biomass ATP, ADP and AMP. ATP in the neutralised extract is measured by the luciferin-luciferase system; ADP by conversion to ATP using pyruvate kinase-phosphoenolpyruvate; AMP by conversion to ATP using myokinase, pyruvate kinase and phosphoenol pyruvate.

Conversion of AMP and ADP standards is quantitative when added to the soil extract, and this procedure is being used to measure the AEC of the soil microbial biomass under different environmental conditions. The AEC of soil from Park Grass was 0·85, characteristic of a metabolically active population. (Brookes, Tate and Jenkinson)

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Effects of environmental conditions on the ATP content of soil. Earlier work (Tate & Jenkinson, *Soil Biology and Biochemistry* (1982), **14** (in press)) showed that ATP can serve as a measure of microbial biomass in soil, with a mean biomass C/ATP ratio of 171. This value was obtained on soils that had been incubated for at least 5 days at 25°C before the ATP and biomass C measurements were made. This pre-treatment may have influenced the ratio and an investigation into the effects of environmental conditions on ATP and biomass C was started. Air drying, or a period of waterlogging caused a large decrease in ATP. The biomass C/ATP ratio is influenced by the temperature of the preliminary incubation; in one soil, incubation at 10°C gave a ratio of 230, compared to a ratio of 168 for incubation at 25°C. (Tate and Jenkinson)

Organic matter in sandy soils in relation to yield

Yield effects. An experiment testing the value of sedge peat to increase the organic matter in a sandy soil at Woburn (*Rothamsted Report for 1978*, Part 2, 83–98; *for 1979*, Part 1, 234) was cropped with winter barley in 1980 and with potatoes in 1981; each crop was grown at four rates of nitrogen.

The amounts of organic matter in the soil did not affect yields of barley. However, potatoes grown in 1981 on this site gave up to 8 t ha^{-1} more yield in soil with 1·95 %C compared with 0·70 %C, presumably due to the increased water-holding capacity of the soil. (Johnston and Poulton)

Soil organic matter and erodibility. Surface soil samples (2–3 cm) from the Organic Manuring Experiment at Woburn were used at the National College of Agricultural Engineering, Silsoe, to determine effects of organic matter on the erodibility of the soil. All treatments from the old (1965–71/72) and new (1980–84/85) phases of the experiment were sampled, and tested for resistance to splash, using a rotating disc simulator (Morin, Goldberg & Seginger, *Transactions of the American Society of Agricultural Engineers* (1967), **10,** 74–77), the detached soil being measured.

Clover leys were the most effective in reducing rain splash, followed by leys sown in 1979 on plots previously enriched with peat (1965–70), leys established on plots that had grown green manures (1966–71/72), and plots receiving straw and farmyard manure. Plots given only fertilisers were the least stable to erosion by rain splash. The type of organic matter appears to be as important as the quantity in reducing soil erodibility. (Poulton, with Miss Suzanne Harper and Dr R. P. C. Morgan, National College of Agricultural Engineering)

Micronutrients and heavy metals

Concentrations of micronutrients in displaced soil solutions as a function of pH. Following work on copper, five air-dried sandy loam soils (Marcham series) with pH values between 5·3 and 7·5 were incubated after wetting with water or 0·01 M-calcium chloride; the most acid soil was also incubated with varying quantities of calcium hydroxide. Manganese, zinc and cobalt were determined in the soil soloutions, and the proportions of metals present in solution as the free ions were estimated using an ion-exchange equilibrium technique.

Concentrations of the three metals in solution decreased as the solution pH rose. The free ions were the predominant metal species in solution at pH 5, but less than half the metal was as the free ion above pH 5·5 for cobalt, pH 6·5 for zinc and pH 7 for manganese. This suggests that complex formation by these metals, unlike that by copper, does not prevent their adsorption or precipitation at high pH values.

Both the original pH of the soil in the field and the pH after adding calcium hydroxide influenced manganese and zinc concentrations in soil solutions and in solutions obtained by extracting soils with buffered diethylenetriaminepentaacetic acid. The field soil pH was also important in controlling adsorption or desorption of manganese from soil samples shaken with dilute manganese solutions at different pH values. This suggests that manganese and zinc, unlike copper, are subject to some not readily reversible 'fixation' reaction when field soils are limed. (Sanders)

Metal toxicity to plants. Last year (*Rothamsted Report for* 1980, Part 1, 254) we reported that trivalent (III) and hexavalent (VI) chromium were equally toxic to oats grown in nutrient solutions. Chromium salts were added to acidic or alkaline Rothamsted soils and oats were grown as a test crop. When Cr(III) salts were added, the amount of Cr in the soil solution was small and increased with decreasing pH; the toxicity and plant uptake of Cr(III) was also greatest at low pH. After addition of 750 μg Cr(VI) g^{-1} large concentrations of Cr remained in the soil solutions and the oats died, but adding 750 μg Cr(III) g^{-1} to the soil only caused greater shoot Cr concentrations and smaller yields. A proportion of the Cr(VI) is reduced to Cr(III) at low pH in the presence of organic matter (*Rothamsted Report for 1979*, Part 1, 231–232), which may reduce toxicity due to added Cr(VI) in acid soils.

Two methods of preparing sewage sludges enriched with single metals have been investigated: sludge was anaerobically digested as in a sewage works either in the presence of Zn, Cu or Ni ('digested'), or the sewage sludge was treated with the metals subsequent to the digestion process ('spiked'). The extractabilities of the metals with ammonium acetate, acetic acid or EDTA were considerably less from 'digested' sludges than from 'spiked' sludges. The same preparations were tested after mixing with a Rothamsted soil in a pot experiment. Oats grown on 'spiked' sludge mixtures yielded 50% less than those on 'digested' mixtures. These large differences in the extractabilities and phytotoxicities of the metals in the 'digested' and 'spiked' sludges show that the latter is of little value for work on the availability to plants of metals in sewage sludge. (McGrath)

Trace element contents of different soil series. The work reported previously (*Rothamsted Report for 1979*, Part 1, 232–233) on trace metal content of five soil series has been extended to 49 topsoil samples of profiles of the Evesham, Hamble, Cegin, Wick and Whimple series. Their total contents of Pb, Zn, Cu, Ni, As, Mn and Cr were determined by X-ray fluorescence spectrometry and the amounts of extractable Pb, Zn, Cu and Ni were determined using standard ADAS methods.

The means and ranges of the total and extractable amounts in the different series are similar to those found before. Although the range of both total and extractable amounts within series is almost as large as the ranges for all soil series, the average contents of the different series differ. The average coefficient of variation lies between 18·2% for the Whimple series and 42·5% for the Cegin series.

Correlation coefficients between total and extractable amounts of metals (Table 6) are often larger for the separate series than for the entire set of samples. Of the 20 values for

TABLE 6

Correlation coefficients between total and extractable amounts of Pb, Zn, Cu and Ni in five soil series

Element	Evesham	Hamble	Cegin	Wick	Whimple	All
Pb	0·82	0·95	0·73	0·96	0·83	0·86
Zn	0·86	0·76	0·17	0·82	0·30	0·42
Cu	0·67	0·98	0·37	0·90	0·82	0·71
Ni	0·58	0·16	0·18	0·48	0·49	0·49

the five soil series, nine are greater than 0·8, suggesting that agriculturally useful information can in some cases be obtained from analyses for total amounts. (Brown)

Soil root relations

Effects of mycorrhizas on cereal growth in the field. The 1980 spring wheat experiment (*Rothamsted Report for 1980*, Part 1, 251) was repeated on an adjacent site. In 1981, inoculation with *Glomus mosseae* increased grain yield by 21% on fumigated plots, and by 7% on non-fumigated soil averaged over all P treatments, whereas there were no effects on yield in 1980. There were no effects of mycorrhizal infection on %P.

Winter barley (cv. Igri) was direct-drilled on the site of the 1980 spring wheat experiment, without application of further treatments. The barley on plots inoculated in 1980 gave 34% more dry matter when they had been fumigated, and 7% more when they had not, averaged over all P treatments. Percentage responses were largest where no P fertiliser was given. Again, bromine uptake was about four times greater on inoculated plots. Inoculation increased the P concentration in young plants, especially on fumigated plots, but not at harvest. This residual effect of inoculation must arise from the different levels of infection in the preceding spring wheat crop. Since the winter barley crop itself had different levels of infection in inoculated and non-inoculated plots at harvest, it is possible that the effects may persist for another year, and this is being tested. (Buwalda, Stribley and Tinker)

Carbon and phosphorus physiology of mycorrhizal plants. Further studies on the fate of $^{14}CO_2$ pulse-fed to mycorrhizal and uninfected leek plants (*Rothamsted Report for 1980*, Part 1, 251) used short (48 h) or long (214 h) 'chase' periods. The growth patterns of the mycorrhizal and uninfected plants were monitored to ensure that plants of similar growth rate and morphology were used for feeding with ^{14}C. The mycorrhizal plants assimilated ^{14}C per unit leaf area at a similar rate to controls, but overall lost 8% more of the total C fixed from the shoots by increased below-ground respiration and loss into the soil. This loss of carbon appears to be compensated by infected plants having a lower percentage of dry matter in their leaves, and so showing an apparently greater assimilation rate per unit dry matter of shoots than the controls. The reasons for this increased leaf hydration, and the rates of photosynthesis by mycorrhizal and non-infected plants, are being studied further, particularly with regard to the %P in the leaves. (Snellgrove, Splittstoesser, Tinker and Stribley)

As part of this study, leek plants were grown at six levels of soil P, with and without mycorrhizal inoculation and harvested at frequent intervals. Whereas uninfected plants (NM) showed smooth downward trends in %P (dry wt basis), inflow for P, relative growth rate (RGR) and fresh wt/dry wt ratio, all these functions increased sharply at the time of rapid spread of infection in mycorrhizal (M) plants and then, from about 40 days on, declined rapidly. The magnitude of the unexpectedly high concentrations of P relative to dry matter in mycorrhizal plants noted by Stribley, Tinker & Rayner (*New Phytologist* (1980), **86**, 261–266) thus depends greatly on time of harvest, but the relation between RGR and %P remained different for M and NM plants, as suggested by the C-loss hypothesis of Stribley *et al.* When %P was expressed on the basis of plant water content there was little change accompanying infection and all plants maintained very constant internal concentrations of P in the liquid phase, despite large ontogenetic changes in relative growth rate and dry matter content. (Stribley, Snellgrove and Tinker)

Modelling infection spread in developing root systems. Our logistic model for spread of

VA infection (*Rothamsted Report for 1980*, Part 1, 252) is:

$$\frac{dL_i}{dt} = SL_i\left(1 - \frac{L_i}{nL_t}\right)$$

where L_i is the length of infected root, L_t the total length of root, and n the maximum fraction of the root system which becomes mycorrhizal, all at time t. S measures the susceptibility of the root system to infection, and has been shown to be independent of time when steady growth is occurring. This concept was tested in pot experiments on wheat and leeks, with three different levels of P. In wheat, fertiliser P reduced S a little, but n greatly, so that L_i was much smaller. In leeks L_i, S and n were little affected, but L_t was greatly increased, thus giving lower percentages of infection at harvest. The well-known effect of P fertiliser in reducing percentage infection can thus arise in quite different ways in different species. The model may be a useful tool for elucidating the mechanism by which environmental change affects mycorrhizal colonisation. (Buwalda, Tinker and Stribley, with Ross, Statistics Department)

Growth of root hairs. The aims were to identify those factors which might influence the growth of root hairs in natural conditions and to produce roots with and without root hairs for use in future studies of the function of root hairs. Root hair growth in solution culture was monitored by measuring the length of root hairs after 3 or 4 days growth of barley and wheat seedlings.

The major factor influencing root hair growth was Ca concentration. With solutions of single Ca salts at concentrations $< 10^{-4}$ M there was no root hair growth, but above this concentration root hair length increased to reach a maximum in the range $1\text{–}5 \times 10^{-2}$ M-Ca, above which it decreased again. When N was supplied as NH_4^+, root hair growth was inhibited at 10^{-3} M-NH_4^+, but this may be largely a pH effect. Additions of polyethyleneglycol 4000, in the presence of Ca, also decreased root hair growth, which may indicate that growth is sensitive to water potential. (Leigh and Branson)

Water relations of wheat root cells. The pressure probe invented by Zimmerman & Steudle (*Plant Physiology* (1978), **61,** 158–163) has been used to study turgor pressure, cell wall elastic modulus and hydraulic conductivity of epidermal and cortical cells of wheat roots grown in Hoagland's nutrient solution. Despite the constancy of the external osmotic pressure the epidermal and cortical cells seem to possess different turgor pressures ($2{\cdot}9 \pm 1{\cdot}0$ bar and $5{\cdot}4 \pm 1{\cdot}6$ bar, respectively). In cortical cells the elastic modulus of the wall was dependent on cell volume which implies that larger (and possibly older) cells are less elastic than smaller cells. Attempts to measure water relations parameters of root hair cells have so far been unsuccessful. (Leigh, with Dr Deri Tomos, Department of Biochemistry and Soil Science, UCNW, Bangor)

Subsoil cultivation

Subsoil fertilisation. In 1981, like 1980, crops generally did not benefit from subsoiling alone, possibly because there was sufficient rain during the latter part of the growing season, when it is expected that subsoiling may make water at depth available to the crop. However, there were no adverse effects of subsoiling and, in some experiments, spring barley yields were increased.

This was the first year of the latest experiment which tests subsoiling alone, and subsoil enrichment with several rates of P and K singly and in combination. Beans, winter wheat, potatoes and spring barley grown in rotation yielded 3·6, 7·7, 61·7 and 5·9 t ha^{-1} respectively. Subsoiling alone or with low rates of P and K increased yields only of barley to 6·4 t ha^{-1}. With the larger rates of P and K in the subsoil yields were increased by 1·1 t ha^{-1} for barley, 0·6 t ha^{-1} for beans and 7·4 t ha^{-1} for potatoes. However, similar amounts of P and K applied to the topsoil gave yields of barley and potatoes equal to those given by the same dressing cultivated into the subsoil whilst bean yields were intermediate between those given by conventional ploughing and enriched subsoil. There was thus little advantage in subsoil placement for barley, wheat or potatoes in 1981. (Johnston and Poulton, with McEwen and Yeoman, Field Experiments Section)

Subsoiling, and subsoil enrichment with P and K as a compound fertiliser were done at Saxmundham on the Rotation I site in summer 1979 with the Wye Double Digger. Wheat, cv. Avalon, gave excellent yields in 1981 with ten plots exceeding 11 t ha^{-1}, and subsoiling had little effect, with conventionally cultivated, subsoiled and subsoil-enriched plots yielding on average 9·84, 9·79 and 9·92 t ha^{-1} respectively. (Johnston and Poulton)

Penetrometer readings after subsoiling experiments. A Bush recording penetrometer (Anderson *et al.*, *Journal of Soil Science* (1980), **31,** 279–296) was used to test mechanical strength of soils on experiments comparing conventional mouldboard ploughing and ploughing plus subsoil cultivation with the Wye Double Digger. Within each experiment all soils to plough depth had very similar resistances at each depth, except for plots which had been direct drilled for a single season. In all experiments cultivation of the subsoil resulted in lower resistances to the penetrometer, including subsoils at Rothamsted and Woburn which had been cultivated with the Wye Double Digger 4 years before the measurements were made. Even more encouraging was the finding that penetrometer readings were less in subsoils in the first experiment at Woburn which was loosened only once in 1973. (Poulton, De Cuyper and Johnston)

Soil and clay structure

Interaction of water with soils and clays. The specific surface of soil is important because it determines its swelling properties. Water can be used as a sorbate for measuring its area, provided allowance is made for water held in micropores smaller than 2 nm, and provided the water sorption isotherms for the surfaces are known. The latter have been confirmed for a number of well-characterised layer silicate minerals spanning the range of microporosity in the illite-smectite group, from ground muscovite to Redhill montmorillonite. The isotherm for muscovite, which has only external surface, corresponded closely with published data for water sorption on other non-porous sorbents. This similarity enables a general isotherm to be used to analyse isotherms for clays and soils for porosity components. For example, the simple application of the Brunauer, Emmett and Teller (BET) equation to the sorption of water on Beavers Bend illite gives a specific surface of 31·7 m^2 g^{-1}. An analysis of the sorption in the multilayer region, however, shows that this illite exhibits a small amount of micropore filling in the BET region, caused by the presence of about 2% smectite, and that the real external surface is only 18 m^2 g^{-1}. This type of analysis will now be applied to the surface properties of soil. (Newman)

Expanding layer-silicate clays are the usual source of soil micropores, and the bulk physical properties of soils depend on how the size of such micropores vary as soil water content changes. Their sizes can be calculated from X-ray diffraction measurements, but few attempts have been made to link X-ray and isotherm data. Using a modified diffractometer, measurements made on a smectite clay mineral, with total specific surface 800 m^2 g^{-1}, have been used to calculate the interlamellar volume over the relative humidity range from 44 to 85%. When applied to the isotherm these measurements showed that multilayer formation was occurring on the external surface of 253 m^2 g^{-1}. This work is now being extended to the mixed layer mica-smectite clays used for the isotherm studies described in last year's report. (Ormerod and Newman)

Soil structure regeneration. In the first test of the natural regeneration of soil structure on Batcombe soil compaction caused a more massive structure and considerable diminution of pores $>60\ \mu m$ in size, to at least 15 cm depth. During the subsequent 18 months, especially during the first summer, this coarse porosity increased in the 0–5 cm layer, and horizontal planar voids formed, but little regeneration of structure occurred at 5–15 cm, so subsoil compaction is likely to be more persistent and damaging than compaction at the surface.

The research has been extended with funds from the EEC, to sites on Hamble and Evesham soils, to find out whether these effects are general or peculiar to certain types of soil. Initial results suggest that compaction had a much more drastic effect on porosity on the Hamble than on the Evesham or Batcombe soils. On the Hamble soil compaction increased the bulk density from 1·25 to 1·42 and decreased yield of spring wheat by 36%. (Newman, with Bullock and Thomasson, Soil Survey)

The influence of particle size distribution on soil physical properties. Soil of the Batcombe series at Rothamsted has a strongly developed fine structure that produces a good tilth, Stackyard series at Woburn has weak structure and slakes readily after cultivation, and Beccles series at Saxmundham has a very coarse structure that resists breakdown. Attempts have been made to explain these differences in behaviour in terms of particle size and packing. Particle size distributions were determined by separating the dispersed soil into nine fractions. Samples of each fraction were remoulded, dried, and their strengths measured. Samples of fractions coarser than 53 μm were all weak, and the strength of the total soil therefore depends on the amounts of the finer fractions. The Beccles series is strongest when remoulded, presumably because this soil is most nearly well-graded in the engineering sense. This soil therefore strongly coheres and once it becomes compact it is likely to remain so.

The soil fractions have also been examined using the scanning electron microscope. Grains larger than 20 μm from the Beccles series were much more pitted than those in the other two soils. It is believed that this roughness enables the grains to help bind the soil together. (Williams)

Effect of crystal thickness on position and intensity of the 020 reflection of lepidocrocite and of boehmite. The identification of minerals from their X-ray diffraction patterns depends on there being characteristic spacings between the planes in the crystals. Identification is difficult when patterns are obtained in which reflections are not found at their normal positions. Displacements of the 020 X-ray reflection of lepidocrocite, a common mineral in soils, and of boehmite from their normal spacings of 0·627 and 0·6107 nm respectively have been observed by several workers and different explanations have been given to account for this. Similar displacements have been reported for layer silicates and attributed to their occurrences as thin crystals. Such displacements are found when appreciable gradients in the structure factor and the Lorentz-polarisation factor occur within the main maximum of the interference function which is increasingly broadened as crystals become smaller. Brown (*Crystal structures and clay minerals and their X-ray identification.* Ed. G. W. Brindley, & G. Brown, *Mineralogical Society Monograph* (1980) No. 5, Chapter 6, p. 365) suggested without proof that the displacements in lepidocrocite and boehmite were caused in the same way. Possible parallel affects on intensities do not appear to have been considered before.

To test the proposal that displacements in lepidocrocite and boehmite could be attributed to thin crystals, diffraction profiles were calculated for crystals ranging from 2 to 10 000 layers thick. The calculations were made so that the intensities for crystals of different thickness were on the same scale. To simulate experimental diffraction patterns, profiles were also calculated for materials consisting of mixtures of crystals of different sizes. The calculations show that increasing displacement and line broadening are associated with decreasing crystal thickness below 50 layers. For lepidocrocite the apparent *d* (020) spacing ranges from 0·814 nm for two-layer crystals, through 0·6327 nm for ten-layer crystals to 0·6268 nm for 100-layer crystals and calculated widths at half-height for Co Kα-radiation are 6·2°, 1·45° and 0·15°. For boehmite the corresponding apparent spacings and widths are 0·807, 0·617 and 0·6107 nm and 6·11°, 1·49° and 0·15°. These values cover the ranges that have been observed experimentally, and the features of published patterns can be explained in terms of diffraction from crystals that are thin in the *b*-axis direction. The peak intensities, as expected, decrease as the crystal size decreases and the reflection becomes broader, but the integrated intensity of the 020 reflections of lepidocrocite and boehmite increase to values 1·66 and 1·84 times that for large crystals. These results show that considerable care is required in choosing appropriate standards for quantitative estimations of poorly crystalline samples.

Similar effects of crystal thickness have been calculated for the 001 and 002 reflections of kaolinite. (Brown)

Solute movement in soil

Simulation of diffusion in soil aggregates and other porous solids. Nitrate and other non-adsorbed solutes are at least partially protected against leaching when they are held within soil aggregates. This has been simulated in two models (*Rothamsted Reports for 1976*, Part 1, 87, *for 1979*, 235) in which only part of the soil solution is assumed to be mobile. In the latter model movement of solute between the mobile and non-mobile phases occurs by diffusion and the aggregates are treated as cubes. Improved versions of the diffusion submodel have been developed and shown to be applicable to spheres and other regular solids. They have been used successfully to simulate the diffusion of bromide out of cubes of chalk of different length of side and from mixtures of these.

Some measurements of nitrate diffusion from soil crumbs made in 1973 were also used for validation. The model satisfactorily simulated diffusion from these crumbs, ranging in size from those with diameter between 0·5–1·0 and 4–5 mm. Diffusion from these relatively small crumbs was rapid and was more than 90% complete within 30 min. (Addiscott and Thomas)

Soil solution extraction with suction cups. Much of our work on nutrient supply and uptake hinges on the question of the composition of the soil solutions. This is very variable, and normal sampling and extraction methods are extremely laborious. We have therefore investigated the use of porous suction cups inserted in the soil through which solution samples may be drawn off at frequent intervals.

Two kinds of suction units were developed, one a miniature unit which can operate up to a suction of 0·3 bar, whilst the other can be used up to 1 bar suction. The concentrations of NO_3-N in soil water samples obtained with these units was compared with that obtained from augered soil samples on a fertilised cultivated bare fallow. Averages from 12 samples or 12 suction cups agreed well, except on one date when heavy rain delayed the soil sampling. The suction cups can be sampled at all times and take less than 10% of the time needed for soil sampling once the cups are in position. However, the results from these are rather more variable than from soil sampling. (Williams, with P. W. Lane, Statistics Department)

Spatial analysis of soil properties

Much effort has been devoted to programming for interpolating and mapping from irregularly distributed data. A satisfactory procedure for general use is to interpolate values by kriging on a fine square grid to produce a regular figure field. The figure field is then passed to Surface II, a graphics program written especially for mapping by the Kansas Geological Survey. The results in the forms of both contour maps and block diagrams are finally drawn on the Benson graph plotter.

A study of co-regionalisation has been started using data on the proportions of sand, silt and clay in the soil of Stackyard field at Woburn. The sand and silt fractions in both topsoil and subsoil have similar patterns of spatial variation, but the clay differs substantially. Knowledge of the co-regionalisation has been used to optimise the estimation of silt in the topsoil of field experimental plots and for mapping Stackyard field.

Trace metal distribution. A study of variation in the available copper and cobalt contents of the topsoil in 3500 fields in south-east Scotland was made in collaboration with the East of Scotland College of Agriculture. The concentration of copper was found to be moderately associated with the parent material of the soil; in particular, soil on the Old Red Sandstone sediments was locally deficient in copper, with less than 1 mg kg^{-1}. Otherwise little relation was found between metal concentration and soil classes. The spatial analysis detected three main components of variation for both copper and cobalt. One extended to about 3 km and was attributed to farm-to-farm variation. A long-range or geological component extended to 15 km. The third component was non-spatial, i.e. nugget, and for cobalt accounted for more than two-thirds of the variation. The concentrations of copper and cobalt were interpolated optimally by kriging and isarithmic ('contour') maps drawn automatically of both the interpolated values and their associated errors. A large part of the region was found to contain less cobalt than the recommended minimum (0·25 mg kg^{-1}). The error was acceptably small for most of the region, and only a small part seemed to need more intensive sampling. (Webster and McBratney)

Spatial variability of soil nitrate and factors affecting its leaching. The spatial variability of soil nitrate is normally large, and it determines the number of soil samples needed per unit area for representative measurement. The variability in different soil layers should also provide information about the leaching process. In October soil samples were taken to 1 m depth at 144 points in a nested sampling design on a 50 × 50 m plot at Rothamsted. NO_3-N concentrations in the top 20 cm of soil ranged from 6 to 60 mg kg^{-1} but more than 80% of the values fell between 16 and 26 mg kg^{-1}.

Some models for soil nitrate leaching are based on capacity factors for water, whilst others compute rates of water movement and hence need hydraulic conductivities. The relative usefulness of such models is clearly influenced by the spatial variability in capacity and rate factors. Simple measures of capacity and rate were obtained from the percentage moisture in the top soil and the rate of fall of the level of water poured into the sampling holes. The moisture percentages were normally distributed and the ratio of the largest to the smallest was 1·5. The rates of fall of water level, measured in the first minute and the subsequent 59 min, were log-normally distributed and the ratio of the largest to the smallest were 31 and 46 respectively. Soil heterogeneity therefore causes especially severe problems for models based on water flow. (Addiscott and Webster)

Pedological studies

Loess soils in Cornwall. Work on the distribution and composition of loess has been extended to Cornwall and the Scilly Isles. The loessial soils occur mainly on the southern side of higher ground, on outcrops of granite, granite-gneiss and serpentine bedrock, and usually on flat or greatly sloping land. On the Lizard peninsula loess forms a nearly continuous mantle 0·5–2·5 m thick on the serpentine outcrop (Traboe and Croft Pascoe series), but it is thinner and discontinuous on the gabbro and granite-gneiss. It covers approximately two-thirds of the Scilly Isles granite, but only 16–22% of the mainland granites.

Compared with the loess in east Devon, the Cornish and Scillies deposits are much coarser, the modal size being >40 μm (compared with 26 μm near Torquay). The heavy minerals in the 16–62 μm fraction are also different from those in the loess of Devon and all other parts of south and east England. Thermoluminescence dating (Wintle, *Nature, London* (1981), **289,** 479–480) has shown that all these loesses are of similar Late Devensian (14 500–19 000 years) age, and in Cornwall this is supported by stratigraphic relationships with head and raised beach deposits. Our results therefore suggest derivation from a different source area.

The Late Devensian loess of south-east England was derived mainly from glacial outwash deposits on the floor of the North Sea, possibly deposited by north-easterly periglacial winds. Outwash deposits were probably not so extensive on higher ground above present sea level, so the most likely alternative source for the Cornish loess was the outwash in the Irish Sea basin. Derivation from this area by north or north-east winds would explain why the loess in Cornwall has accumulated mainly to the south (in the lee) of higher ground, and is more widespread on the Scilly Isles. Its absence from slate areas, however, probably reflects more intense post-depositional erosion on this bedrock type, either by gelifluction in cold conditions during the very late Devensian or by soil erosion since the advent of agriculture. (Catt, with Staines, Soil Survey)

Protein extraction

The work on the factors causing the decline in protein extractability as leaves mature is now finished. There is little or no destruction of β-carotene (pro-vitamin A) when moist leaf protein from several species, e.g. barley, elder, field beans, lucerne, nettles, potato and wheat, is kept in the dark at room temperature for 2 or 3 weeks preserved with acetic acid or sodium chloride. Protein from Brussels sprout tops and rape, on the other hand, loses a significant amount of carotene in a week. Even at -20°C there is some loss of carotene in a few months with sodium chloride. The nature of this unexpected reaction is obscure.

The relevant dimensions of a unit in which leaves on a grid are pulped by dropping a weight on them have been defined and a family-sized unit operated by a treadle will be made, We already have a hand-press suitable for work on this scale, so that we should have a system which could extract juice in one operation from about 500 kg leaf h^{-1}. (Pirie)

Analytical and isotopes section. This year 103 000 digestion and chemical analyses were done, 16·3% more than last year. Of the total, 7·1% were for other departments. Attempts are being made to use an Apple microprocessor to pick and evaluate peaks produced by samples in the automated analysis of cations, using atomic absorption. (Cosimini, Messer, Pope, Brown and Thompson)

Over 11 000 analyses were made in the isotopic section, including analyses for ATP on the scintillation counter. (Smith)

Staff and visiting workers

O. Talibudeen retired in June after 35 years at Rothamsted, R. J. B. Williams retired in December after 25 years and W. Lazarus retired after 10 years. J. Ashworth resigned in March to take up an appointment with Norwest Soil Research in Edmonton, Canada, and A. P. Whitmore was appointed in September.

N. W. Pirie gave papers at the Kellogg Foundation Symposium on Food Proteins in Cork, at the International Conference on Agricultural Engineering in Bangkok and at the Platinum Jubilee of the C. S. Azad University of Agriculture and Technology in Kanpur. He also attended a meeting of the Leaf Protein Research Coordination Committee in Calcutta. P. B. Tinker was a keynote speaker in a symposium on factors affecting yield and presented a series of seminars at the University of Guelph, Canada, in May. R. Webster visited the Netherlands in February to discuss recent developments in research and computer applications in soil science, geostatistics and remote sensing, and the Centre de Géostatistique, Fountainebleau, France, to discuss research on the spatial analysis of soil. He presented a paper and served as session chairman at the International Society of Soil Science Colloquium on Soil Information Systems in Paris, France, in September. S. P. McGrath visited Amsterdam in September to attend an International Conference on heavy metals. T. M. Addiscott visited Centro de Energia Nuclear na Agricultura, Piracicaba, Brazil, in December to investigate the possibilities of cooperation in the simulation of field experiments on nitrogen behaviour, and D. S. Powlson went to France in December for discussions on the efficiency of use of nitrogen fertiliser by cereals.

J. A. Catt was awarded a D.Sc. by Hull University, J. R. F. Menk a D.Phil. by Oxford University, and A. Gildon a Ph.D. by London University.

P. B. S. Hart arrived from New Zealand as a research student and G. J. T. Scott, attached to Reading University, arrived as a CASE student. J. G. Buwalda, from New Zealand, G. V. E. Pitta, from Brazil, Gamin M. Wang, from Brazil and R. Harrison continued their studies. A. B. McBratney completed his studies and left to take a post with CSIRO Division of Soils in Australia. Karen S. Eide, attached to Institute of Archaeology, London, and P. J. Reynolds, attached to London University spent the year as research students with us. A. R. Bromfield left for Dakar, Senegal, on secondment.

Dr K. Tate returned to New Zealand, Dr N. Miyauchi returned to Japan, Mr X. de Cuyper returned to Belgium and Dr C. Dimase returned to Italy, all having completed their term here. We welcomed Dr R. H. Fox of Pennsylvania State University in June and Dr K. D. Singh from Indian Agricultural Research Institute New Delhi in October. Mr Weider, from the Geography Department, Bar-Ilan University, Israel, spent 5 months here, and Mr Xu Jiyan arrived from China, both to work jointly with this Department and the Soil Survey. Mr Shen Shan-min from China remained throughout the year.

Publications

Book

1 (Boels, D., Davies, D. B.) & Johnston, A. E. (1982) *Soil degradation.* Proceedings of the EEC Seminar held in Wageningen, Netherlands. October 1980. Rotterdam: A. A. Balkema, 280 pp.

Theses

2 Abu Bakar, Mohammed Zahari Bin (1981) *The chemical behaviour of acid sulphate soils with special reference to waterlogged conditions.* Ph.D. University of London.

SOILS AND PLANT NUTRITION DEPARTMENT

3 GILDON, A. (1981) *The effect of vesicular–arbuscular mycorrhizal fungus on the uptake of heavy metals by plants.* Ph.D. University of London.

4 MENK, J. R. F. (1981) *Mathematical techniques applied to soil survey.* D.Phil., University of Oxford.

GENERAL PAPERS

5 ADDISCOTT, T. M., (DAVIDSON, J. M., HARMSEN, K., LEFELLAR, P. A., PARTON, W. J., RAO, P. S. C.), RAYNER, J. H., (SMITH, K. A. & WAGENET, R. J.) (1981) Migration processes in soils. In: *Simulation of nitrogen behaviour of soil plant systems.* M. J. Frissel & J. A. van Veen). Wageningen: PUDOC, pp. 33–37.

6 CATT, J. A. (1981) British pre-Devensian glaciations. In: *The Quaternary in Britain.* Ed. J. Neale & J. Flenley. Oxford Pergamon Press Ltd, pp. 9–19.

7 CATT, J. A. (& MADGETT, P. A.) (1981) The work of W. S. Bisat, F.R.S., on the Yorkshire coast. In: *The Quaternary in Britain.* Ed. J. Neale & J. Flenley. Oxford: Pergamon Press Ltd, pp. 119–136.

8 CATT, J. A. & WEIR, A. H. (1981) Soils. In: *The evolving earth.* Ed. L. R. M. Cocks. London: British Museum (Natural History), Cambridge University Press, Chapter 5, pp. 63–85.

9 COOKE, G. W. (1981) Managing the mineral cycle. *Proceedings of the Nutrition Society* **40,** 295–314.

10 JENKINSON, D. S. (1979) The nitrogen cycle in long-term field experiments. *Philosophical Transactions of the Royal Society of London, B* **296,** 563–571.

11 JOHNSTON, A. E. (1981) Accumulation of phosphorus in a sandy loam soil from farmyard manure (FYM) and sewage sludge. In: *Phosphorus in sewage sludge and animal wastes slurries.* Proceedings of the EEC Seminar held in Gromingen, Netherlands, June 1980. Ed. T. W. G. Hucker & G. Catroux. Dordrecht: D. Reidel Publishing Company, pp. 273–296.

12 JOHNSTON, A. E. (1982) The effect of farming systems on the amount of soil organic matter and its effect on yield at Rothamsted and Woburn. In: *Soil degradation.* Proceedings of the EEC Seminar held in Wageningen, Netherlands, October 1980. Ed. D. Boels, D. Boels, D. B. Davies & A. E. Johnston. Rotterdam: A. A. Balkema, pp. 187–202.

13 MOSSE, B., STRIBLEY, D. P. (& LETACON, F.) (1981) Ecology of mycorrhizae and mycorrhizal fungi. *Advances in Microbial Ecology* **5,** 137–210.

14 PIRIE, N. W. (1980) Water weed uses. *Water Spectrum* **12** (3), 43–49.

15 PIRIE, N. W. (1981) Weed control. *Nature, London* **290,** 356.

16 PIRIE, N. W. (1981) What are the most useful and easily available sources of potassium? *Diarrhoea Dialogue* **5,** 7.

17 PIRIE, N. W. (1981) Would food and health services benefit from a more intimate union? *Ecology of Food Nutrition* **10,** 257–259.

18 PIRIE, N. W. (1981) Cosmobiochemistry. *Trends in Biochemical Science* **6** (12), ix–x.

19 PIRIE, N. W. (1982) Leaf protein as a food source. *Experientia* **38,** 28–31.

20 PIRIE, N. W. (1981) Sir (Edward) John Russell (1872–1965). *Dictionary of National Biography, 1961–1970* pp. 908–909.

21 TINKER, P. B. (1981) Levels, distribution and chemical forms of trace elements in food plants. *Philosophical Transactions of the Royal Society of London B* **294,** 41–55.

22 WEBSTER, R. (1981) Experience of kriging from field measurements of soil properties. In: *Traitement Informatique des Données de Sol*, Tome **1.** Ed. M.-C. Girard, Paris, Grignon: Institut National Agronomique, pp. 101–109.

23 WEBSTER, R. (1981) Soil survey, its quality and effectiveness. In: *Soil resources inventories and development planning*. Soil Management Support Services, U.S. Department of Agriculture, Washington, D.C., pp. 53–62.

24 WOODHEAD, T. & CATT, J. A. (1981) Rothamsted Subject Day 1980. *Soil and Water* **9** (1), 34.

PAPER IN ROTHAMSTED REPORT, PART 2

25 WIDDOWSON, F. V., PENNY, A. & HEWITT, M. V. (1982) Results from the Woburn Reference Experiment. III. Yields of the crops and recoveries of N, P, K and Mg from manures and soil, 1975–79. *Rothamsted Experimental Station. Report for 1981*, Part 2, 5–21.

RESEARCH PAPERS

26 ADDISCOTT, T. M. (1982) Simulating diffusion within soil aggregates: A simple model for cubic and other regularly-shaped aggregates. *Journal of Soil Science* **33,** 37–45.

27 ASHWORTH, J. & RODGERS, G. A. (1981) The compatibility of the nitrification inhibitor, dicyandiamide with injected anhydrous ammonia. *Canadian Journal of Soil Science* **61,** 461–463.

28 ASHWORTH, J., WIDDOWSON, F. V., PENNY, A., GIBBS, A. J., HODKGINSON, R. A. & HEWITT, M. V. (1982) Results from an experiment on permanent grass evaluating the cumulative effects of aqueous urea, injected alone or with a nitrification inhibitor, with those of 'Nitro-Chalk'. *Journal of Agricultural Science, Cambridge* **98,** 141–154.

29 BARRACLOUGH, P. B. & TINKER, P. B. (1981) The determination of ionic diffusion coefficients in field soils. I. Diffusion coefficients in sieved soils in relation to water content and bulk density. *Journal of Soil Science* **32,** 225–236.

30 BARRACLOUGH, P. B. & TINKER, P. B. (1982) The determination of ionic diffusion coefficients in field soils. II. Diffusion of bromide ions in undisturbed soil cores. *Journal of Soil Science* **33,** 13–24.

31 BLOOMFIELD, C. & MCGRATH, S. P. (1982) A comparison of the extractabilities of Zn, Cu, Ni and Cr from sewage sludges prepared by treating raw sewage with the metal salts before or after anerobic digestion. *Experimental Pollution* (Series B), **3,** 193–198.

32 BROOKES, P. C. & POWLSON, D. S. (1981) Preventing phosphorus losses during perchloric acid digestion of sodium bicarbonate soil extracts. *Journal of the Science of Food and Agriculture* **32,** 671–674.

33 BROOKES, P. C. (1982) Correction for seed-P effects in L-value determinations. *Journal of the Science of Food and Agriculture* **33,** 329–335.

34 BURGESS, T. M., WEBSTER, R. & MCBRATNEY, A. B. (1981) Optimal interpolation and isarithmic mapping of soil properties. IV Sampling strategy. *Journal of Soil Science* **32,** 643–659.

35 CATT, J. A. (1981) Quaternary history of the Hertfordshire area. *Transactions of the Hertfordshire Natural History Society* **28** (4), 27–54.

36 (CERRI, C. C.) & JENKINSON, D. S. (1981) Formation of microbial biomass during the decomposition of ^{14}C labelled ryegrass in soil. *Journal of Soil Science* **32,** 619–626.

SOILS AND PLANT NUTRITION DEPARTMENT

37 (COOPER, K. M.) & TINKER, P. B. (1980) Translocation and transfer of nutrients in vesicular–arbuscular mycorrhizas. IV. Effect of environmental variables on movement of phosphorus. *New Phytologist* **88,** 327–339.

38 GILDON, A. & TINKER, P. B. (1981) A heavy metal-tolerant strain of a mycorrhizal fungus. *Transactions of the British Mycological Society* **77,** 648–649.

39 GOULDING, K. W. T. (1981) Potassium retention and release in Rothamsted and Saxmundham soils. *Journal of the Science of Food and Agriculture* **32,** 667–670.

40 IMAI, H., GOULDING, K. W. T. & TALIBUDEEN. O. (1981) Phosphate adsorption in allophanic soils. *Journal of Soil Science* **32,** 555–570.

41 LEIGH, R. A., (AHMAD, N. & WYN JONES, R. G.) (1981) Assessment of glycinebetaine and proline compartmentation by analysis of isolated beet vacuoles. *Planta* **153,** 34–41.

42 MCBRATNEY, A. B. & WEBSTER, R. (1981) Detection of ridge and furrow patterns by spectral analysis of crop yield. *International Statistical Review* **49,** 45–52.

43 MCBRATNEY, A. B. & WEBSTER, R. (1981) Spatial dependence and classification of the soil along a transect in Northeast Scotland. *Geoderma* **26,** 63–82.

44 MCBRATNEY, A. B., WEBSTER, R. & BURGESS, T. M. (1981) The design of optimal sampling schemes for local estimation and mapping of regionalized variables. I. Theory and method. *Computers and Geosciences* **7,** 331–334.

45 MCBRATNEY, A. B. & WEBSTER, R. (1981) The design of optimal sampling schemes for local estimation and mapping of regionalized variables. II. Program and examples. *Computers and Geosciences* **7,** 335–365.

46 POWLSON, D. S. (1981) Effect of cultivation on the mineralisation of nitrogen in soil. *Plant and Soil* **57,** 151–153.

47 POWLSON, D. S. & JENKINSON, D. S. (1981) A comparison of the organic matter, biomass, adenosine triphosphate and mineralisable nitrogen contents of ploughed and direct drilled soils. *Journal of Agricultural Science, Cambridge* **97,** 713–721.

48 SMITH, G. J. & TALIBUDEEN, O. (1981) The ^{40}K and ^{214}Bi (from ^{238}U) contents of Rothamsted soils determined by gamma spectrometry. *Journal of Soil Science* **32,** 593–603.

49 STRIBLEY, D. P., TINKER, P. B. & SNELLGROVE, R. (1981) Phosphorus and carbon relationships in plants infected with vesicular–arbuscular mycorrhizal fungi. *Journal of the Science of Food and Agriculture* **32,** 627.

50 (WALKER, R. R.) & LEIGH, R. A. (1981) Characterisation of a salt-stimulated ATPase activity associated with vacuoles isolated from storage roots of red beet (*Beta vulgaris* L.). *Planta* **153,** 140–149.

51 (WALKER, R. R.) & LEIGH, R. A. (1981) Mg^{2+}-dependent cation-stimulated inorganic pyrophosphatase associated with vacuoles from storage roots of red beet (*Beta vulgaris* L.). *Planta* **153,** 150–155.

52 WEBSTER, R. & MCBRATNEY, A. B. (1981) Soil segment overlap in character space and its implications for soil classification. *Journal of Soil Science* **32,** 133–147.

53 (WILSON, P.), BATEMAN, R. M. & CATT, J. A. (1981) Petrography, origin and environment of deposition of the Shirdley Hill Sand of southwest Lancashire, England. *Proceedings of the Geologists' Association* **92,** 211–229.

54 (WURR, D. C. E.), DARBY, R. J. & (FELLOWS, JANE R.) (1981) The effect of cold storing pre-germinated lettuce seeds on radicle development and seedling emergence. *Annals of Applied Biology* **97,** 335–343.