Report for 1980 - Part 1

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Soils and Plant Nutrition Department

P. B. Tinker

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P. B. TINKER

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Introduction

No major new developments occurred in the year, the main aim being to consolidate the changes of the previous 2 years.

Heavy emphasis on nitrogen in soils and plants is continuing, with the first results of the nitrogen balance programme using ^{15}N just beginning to appear. Work on nitrification inhibitors continues, though the effort is being reduced and redirected. The most important new project is our attempt to develop methods of predicting nitrogen requirements on particular fields, using the existing fundamental studies on nitrate leaching and nitrogen mineralisation as a basis.

The yield variation programme is now producing interesting results, though it must still be considered to be in its early stages. Of the six sites on which we are working, three produced crops with over 10 t grain ha^{-1}. Information on the development and physiology of very heavy crops is therefore being obtained as planned. The computer modelling of wheat growth is proceeding satisfactorily, though the below-ground aspects in particular may give problems. Our collaboration with ICI has produced, for the first time, quantitative evidence of the value of a loess (silt) admixture in soil profiles for the attainment of very high yields.

Similar monitoring is in progress on the subsoil cultivation and fertiliser placement work, though low yield responses in 1980 made this a poor year for study of these techniques.

Our collaboration with the Soil Survey in studying the factors controlling the regain of structure after damage is now well established, and our understanding of how the lost porosity in damaged Rothamsted soils is reformed by natural wetting and drying is much greater than before. The project will now deal with soils which are known to be structurally difficult.

The first results of the reorganisation of the trace metal programme are appearing, with work on the speciation of trace metals in soil solutions, and the plant toxicities of metals complexed in digested sewage sludge. The ranking of metal toxicity appears to differ from the one obtained with inorganic salts applied to soil.

The first results on the investigations of phosphorus in soil biomass are given here; together with the work on mycorrhizas, this represented a deliberate change of emphasis towards the more biological aspects of phosphorus availability. It seems clear that biomass phosphorus is relatively large in grassland soils.

During the year a successful and well-attended Subject Day dealing with basic soil research was held, in which the department was heavily involved. Two laboratories for routine analysis, including Kjeldahl analysis for nitrogen, have been completely refitted, and were taken into use during the year, giving a great increase in convenience and ease of operation.

Yield variation

Results from this programme are now accumulating. The Department's work can be classified under three heads: field experimentation and monitoring, modelling, and soil capability studies. Of these the first takes by far the largest staff time and effort. Six sites are now being studied, at different levels of intensity: the major interdisciplinary experiment at Rothamsted (see p. 18), a smaller multifactorial trial at Woburn, and relatively simple trials at Saxmundham and on three commercial farms selected for their known ability to obtain very high yields.

The principal aim of the programme is to determine the methods and inputs required to reach very high yields of winter wheat on major soil types, or to be able to state with certainty why such yields cannot be achieved. 'Very high yield' has not been defined exactly, but at present it is taken to imply a yield in the vicinity of 10 t ha^{-1}.

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Our perception of the problem is changing. At first there was uncertainty over our ability to get very high yielding crops with which to work and we saw the growing of these as our first task—this was one reason for having experiments on farmers' fields, in addition to the need to get results and experience from a wider range of soils, and the benefits of direct contact with farmers able to obtain such yields. However, this year three of our six sites had treatment yields of over 10 t ha^{-1}, a result which is greatly to the credit of those responsible for the agronomy on them. It is notable that no one treatment level or particular combination of treatments was outstandingly important on any site (assuming that a reasonable amount of N is applied), and that the very high yields were obtained by relatively small benefits accumulating from different treatments, on top of a generally good yield level.

If this pattern continues, we may be able to regard the first step in this programme as successfully completed. The problem will then be, firstly to determine whether the best treatment combinations giving the outstanding yields could have been predicted in advance. Our programme on N fertiliser prediction, using these same sites, is very relevant to this (p. 249). Secondly, we shall need to direct our attention to other sites and soils, with no previous record of high yields, to see whether these results can be duplicated there. The studies on soil capability (p. 247) are important for the choice of such sites in the future.

Field experimentation. By far the largest of the six experiments, which also received the most intensive monitoring and provided the most detailed data, was that at Rothamsted, reported in the Multidisciplinary Activities section of this report (p. 18). The experiment at Woburn, on Blithe series soil, was designed to allow comparisons with Rothamsted. It compared six of the eight two-level factors tested at Rothamsted and had extra plots with a range of N rates, but fungicides and aphicides were given basally, as these were not expected to interact with soil differences. Hustler wheat, sown either on 12 or 29 October at Woburn, was compared with the same variety sown either on 20 September or on 19 October at Rothamsted. Irrigation was given whenever the soil moisture deficit exceeded 25 mm.

Smaller experiments were made at Saxmundham and on three farms on contrasting soil series within a 20 mile radius of Rothamsted where there was a record of high yields. Wheat is extensively grown on these soil series, which are all heavy clays. The sites were in Bedfordshire at Billington where the soil is Evesham series developed in Gault Clay Head over Gault Clay; at Maulden where the soil is Hanslope series developed in Chalky Boulder Clay, and at Hexton in Hertfordshire where the soil is Burwell series which is developed in Chalk Marl Head over Chalk Marl. Each experiment tested a combined treatment of fungicides and systemic insecticides in all combinations with nil and four levels of nitrogen fertiliser, applied either split or singly. The rates of nitrogen applied to these three sites were chosen, by taking into account the previous cropping and soil analysis for mineral N, from a six-level N scale (45–195 kg N ha^{-1}). The varieties used were Flanders sown 14 October 1979 at Billington, Hustler sown 18 October 1979 at Maulden and Brigand sown 2 October 1979 at Hexton.

Measurements of rainfall, dry matter and nutrient accumulation, final yield, disease incidence, soil water content, root development, soil mineral nitrogen, and plant stem nitrate were made on all sites except Saxmundham, where yield, rainfall and soil nitrogen only were measured. Much of the data remains to be processed and it is impossible to report in full on the work, but some of the main results are given here.

Yield and dry matter. The best combination of treatments gave good yields at all sites by normal standards. The lowest of these was at Maulden (6·7 t ha^{-1}) where take-all

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(*Gaeumannomyces graminis*) occurred, but elsewhere maximum yields were extremely good: Billington 8·6, Saxmundham 10·1 and Hexton 10·5 t ha⁻¹. At Woburn the overall mean yield of grain was 8·52 t ha^{-1} (Table 1); the comparable yield at Rothamsted was

TABLE 1

*Grain yield with each factor tested at Woburn, as means of all other factors (t ha^{-1} at 85% DM). In brackets; nearest Rothamsted equivalent treatment means**

Sown 12 October	8·83 (10·56)	Sown 29 October	8·22 (9·51)
Fertiliser nitrogen 90 kg ha^{-1}	8·35 (9·74)	150 kg ha^{-1}	8·70 (10·34)
Single N application	8·68 (9·98)	Divided N application	8·36 (10·10)
N applied early	8·35 (9·81)	N applied late	8·70 (10·27)
Irrigation to limit deficit to 25 mm	8·52 (10·11)	None	8·53 (9·97)
Aldicarb 5 kg ha^{-1} to seedbed	8·51 (10·11)	None	8·54 (9·97)

* Means of plots given fungicide and aphicide in summer. Note that the sowing dates at Rothamsted were 20 September and 19 October and the nitrogen rates 105 and 175 kg ha^{-1}

10·04 t ha^{-1}. The best mean yield from any combination of three treatments at Woburn (sown 12 October) was 9·16 t ha^{-1}, whereas the mean yield of the most closely comparable plots at Rothamsted (sown 19 October) was 9·74 t ha^{-1}, but 11·34 t ha^{-1} for the September sowing. Rothamsted grain yields were always greater than those from corresponding treatments at Woburn. The exponential growth phase was maintained at Billington and Maulden up to the anthesis samplings in mid-June, when dry matter accumulation rate became linear to mid-July. At Hexton the exponential growth phase was maintained beyond mid-June to give a maximum total dry matter of 18·4 t ha^{-1} in mid-July compared with 12·8 at Billington and 13·8 t ha^{-1} at Maulden. Maximum dry matter values were 15·2 t ha^{-1} at Woburn and 17·7 t ha^{-1} at Rothamsted, measured in mid-August.

At Woburn, final stem dry weight was significantly increased only by the earlier sowing date (7·4 *v.* 6·7 t ha^{-1} dry weight) and by irrigation (0·47 t ha^{-1}), but only

TABLE 2

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

Treatment	Experimental site					
	Hexton		Billington		Maulden	
Aphicide/Fungicide	None	Sprayed	None	Sprayed	None	Sprayed
Nitrogen						
Nil	6·73	6·76	4·73	4·41	4·92	5·61
45					5·42	5·92
75	8·75	9·18			5·35	6·22
105	9·04	9·88	6·58	7·84	5·82	6·31
135	9·27	10·30	7·16	7·99	5·71	6·41
165	9·21	10·39	7·36	8·40		
195			6·96	8·46		

	Saxmundham	
	None	Sprayed
Nil	5·74	6·52
80	7·99	9·03
120	8·65	9·28
160	9·00	10·14

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the former was significant at the 5% level. Plant numbers established were 327 m^{-2} from the earlier and 284 m^{-2} from the later sowing, both being larger than comparable figures at Rothamsted. Though maximum shoot numbers in April (1519 m^{-2} for early sown and 1082 m^{-2} for late) were about 20% smaller than at Rothamsted, numbers of ear bearing shoots at anthesis (605 m^{-2} for early, 489 m^{-2} for late) were larger. Leaf area indices (LAI) and most other parameters except ear size and grain weight were consistently larger in the early sown crops. The yield response to the higher N rate reflected its effect on tillering and leaf area index but the early advantage in shoot numbers and dry matter from dividing the N dressing, or from giving it all early was lost by mid-May and reversed by anthesis. Thus stimulation of early growth with nitrogen reduced final grain yield.

At Billington and Maulden 326 and 313 plants m^{-2} were established, but at Hexton a very low seed rate gave only 164 plants m^{-2}. By mid-July ear numbers had stabilised at 515, 566 and 358 m^{-2} at Billington, at Maulden and at Hexton. However the Hexton crop had more than compensated for the lower numbers by its large ear weight. (Widdowson, Darby, Penny and Hewitt, with Welbank and Taylor, Botany Department)

Nitrogen in soils under winter wheat during winter. All six experiments were used to provide information on the fate of mineral nitrogen during winter, as an aid to the interpretation of nitrogen uptake data and to test the method of predicting nitrogen requirement (p. 249).

In autumn, NO_3-N in these soil profiles ranged from 155 kg N ha^{-1} at Woburn, to 60 kg N ha^{-1} at Saxmundham and Billington. In general two-thirds of the measured NO_3-N was in the top 30 cm of soil at this time of year, and the 60–90 cm horizon never contained more than 20 kg N ha^{-1}.

In February the amount of NO_3-N in the 0–30 cm horizon had diminished everywhere either because of crop uptake or by leaching, but in the two lower horizons amounts showed no consistent pattern. At both Rothamsted and Woburn, NO_3-N in the two lower soil horizons decreased under the early sown crop, but increased under the later sown crop. NO_3-N diminished at all depths between February and April, to 45 kg ha^{-1} at Maulden and to nil under the early sown wheat at Rothamsted.

The amount of NH_4-N in soils was remarkably large in October, when the profiles contained from 30–70 kg N ha^{-1}, mostly in the surface horizon. Amounts of NH_4-N decreased in all samples between October and February, then increased in the surface horizon everywhere, but not at the lower depths. (Widdowson, Darby and Bird)

NO_3-N in wheat stems. Simultaneously with the soil sampling the NO_3 content in plant stems was estimated. In general this related well with the amounts of mineral N found in the soil in autumn. In December early sown wheat contained more NO_3-N than late sown (Woburn 780 *v.* 480; Rothamsted 860 *v.* 730 mg kg^{-1}). By 1 February NO_3-N in the early sown wheat at Rothamsted had declined to 750 mg kg^{-1}, but increased to 830 mg kg^{-1} in the later sown crop, paralleling the changes in soil nitrate. At Woburn NO_3-N in February had declined for both sowings. NO_3-N concentration in stems declined to zero by mid-April on all plots without fertiliser N. (Widdowson, Williams, Darby and Bird)

N uptake and percentage composition of crop. In autumn %N, like NO_3 content, was larger in the early sown crop and again in spring this trend was reversed. However, at all times the early sown crop always contained more total N, because of the larger crop size. Maximum N uptake at harvest was 206 kg ha^{-1} at Rothamsted (with 175 kg fertiliser N ha^{-1}) and 189 at Woburn (with 150 kg N ha^{-1}). At harvest, the nitrogen taken up by the wheat without fertiliser nitrogen was 131, 97, 89 and 85 kg N ha^{-1} at Maulden, Hexton

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Billington and Saxmundham respectively, confirming the expected differences in supply of nitrogen from the soil. With the largest rate of nitrogen fertiliser, the contents in the crops at harvest were 162, 205, 182 and 182 kg N ha^{-1} respectively. (Widdowson, Penny, Darby and Hewitt, with Welbank and Taylor, Botany Department)

Diseases. Foliar pathogens were not severe on any site though there was a little mildew at Billington and Maulden and brown rust at Hexton; foot rots were also present at Billington. The outstanding disease problem was take-all at Maulden, which was severe over the whole experiment and probably caused the relatively poor maximum yields there. (Prew, Plant Pathology Department, with Darby)

Growth and nutrient uptake rates of winter wheat roots. This work aims to measure root growth of high yielding winter wheat crops with different treatments, to assess the relative importance of mass flow and diffusion as nutrient supply mechanisms at various stages throughout growth and to provide data for a model of winter wheat growth.

Roots were sampled to 1 m depth using the technique of Welbank *et al.* (*Rothamsted Report for 1973*, Part 2, 26). In December roots had reached depths of at least 60 cm on early-sown plots and 30 cm on late-sown plots at both Rothamsted and Woburn, corresponding to average extension rates of at least 8 mm day^{-1}. By mid-April roots on all five sites had reached a depth of at least 1 m, irrespective of sowing date. By mid-May the amount of root on early and late sown plots had risen to 22 and 17 km m^{-2} at Rothamsted and to 24 and 10 km m^{-2} at Woburn. At this stage some 50–60% of the roots were in the top 20 cm of soil, and root distribution with depth was reasonably described by an exponential decay function.

Nutrient inflows were calculated using Williams' equation (*Australian Journal of Biological Science* (1948) **1**, 333). During the period mid-March to mid-April the largest inflows at Rothamsted were 7·6, 1 and 7·2 $\mu g\ m^{-1}\ day^{-1}$ for N, P and K, respectively, and in the period mid-April to mid-May 23, 2·6 and 26 $\mu g\ m^{-1}\ day^{-1}$. The values for equivalent plots at Woburn were 11, 1·7 and 14 in the first period and 22, 3 and 28 in the second period. All values are for late-sown plots which had received a single, late dressing of N at the largest rate. The increased inflows coincided with the period when shoot growth was rapid compared with root growth. (Barraclough and Leigh)

Water use. Soil water was measured weekly using a neutron soil moisture meter. The soil water deficit reached a maximum of 102 mm on unirrigated plots at Woburn on 12 June, after which it gradually decreased. A similar pattern was observed at Billington (maximum deficit of 96 mm on 30 May), Hexton (122 mm, 26 June), Maulden (95 mm, 12 June) and Rothamsted (110 mm, 7 August).

A small part of the crop at each site was covered from anthesis (12–26 June) until maturity to maximise droughting. Moisture measurements on these crops showed that water was extracted most deeply at Rothamsted and Hexton (more than 1·75 m) and less at Maulden (1·65 m) and Woburn and Billington (1·45 m). Hand samples of crops harvested from under the covers indicated that the degree of droughting attained had not been sufficient to reduce grain yields, and neither at Rothamsted nor Woburn was there any response to irrigation. (Weir, with Welbank, Botany Department)

Winter wheat modelling. The processes and structures to be included in the wheat model being prepared as part of the four-institute study of factors affecting winter-wheat yields have been chosen, and over half of them have been defined in detail. Submodels for root growth and root distribution with depth and for evapo-transpiration have

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been written as computer programs and compared with existing data and new root measurements (see p. 246).

Some comparisons have been made between observed growth stages for Rothamsted crops and a winter-wheat model prepared by Dr J. Ritchie of Texas, that pays particular attention to these stages. This has given useful experience, particularly in the way in which changes in timing of the growth stages may be caused by changes in model parameters. An adaptation of the same model to barley in place of wheat is reported elsewhere (see p. 166). (Rayner and Weir)

Effect of soil type on 1979 yields of winter wheat. Soil series for 630 fields in the 1979 ICI Ten Tonne Club Survey (made available by Mr J. D. Hollies of ICI Ltd) were identified from Soil Survey maps, inferred from geological maps or established by visits to farms. Yields of wheat at these sites ranged from 11·7 to 3·6 t ha^{-1}, mean 6·9 t ha^{-1}. Yields of 10 t ha^{-1} or more were achieved at only 15 sites, on Bromyard, Teme, Marshborough, Beccles, Hanslope, Thorner, Sherborne, Hook, Park Gate, Blacktoft, Adventurers, Burlingham and Hall Series. It is notable that loess forms all or part of the profile in 46% of these soils, but only in 18% of the total 630 named soils.

For series with seven or more sites, the mean yields ranged from 9·2 to 5·4 t ha^{-1}. The range of yields within series also varied widely, however, for example Hanslope series (42 sites) range 10·4–4·5 and Sherborne series (28) 10·2–4·4. The wide ranges imply that many soils are capable of yields of over 10 t ha^{-1} in appropriate circumstances, but that the ease with which this may be achieved varies. Thus in the survey Batcombe series gave moderate yields, mean 6·3 and range 7·5–5·0 t ha^{-1}, whereas a 1979 wheat experiment on Batcombe series at Rothamsted gave a 16-plot mean yield of 11·0 t ha^{-1}.

Mean values were also calculated for higher soil classes and for soils of different texture. *Ground water gley soils* had a mean yield of 7·4 t ha^{-1}, *Peat soils* 7·3, *Brown soils*, 7·0, *Surface water gley soils* and *Pelosols* 6·7, and *Lithomorphic soils* (all *Rendzinas*) 6·6 t ha^{-1}. Within the *Brown soils*, stagnogleyic brown earths (mean 6·1 t ha^{-1}), yielded much less well than the other typical brown earths (7·5). Soils with coarse loamy over gravelly texture, mainly Hall series, had a mean yield of 8·8 t ha^{-1}, peaty soils 7·3, fine silty soils 7·2, fine loamy over clayey soils, 6·9 and clayey soils 6·6. Silty soils gave mean yields of only 6·4 t ha^{-1}, but these were mainly shallow silts over chalk (*Rendzinas*) and the relatively small yields may depend more on shallowness than texture. The good yields on fine silty soils and the large proportion of loessic soils giving over 10 t ha^{-1} show the value of silt as a soil component providing that the soils are deep enough to give adequate available water. (Catt, Weir and Rayner)

Investigations on nitrogen

Recovery of ^{15}N labelled fertiliser by winter wheat on Broadbalk. Equal amounts of 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. Application rates were in practice a little less than those on the main plots (Table 3). Those parts of the main plots not receiving labelled N were given unlabelled N at their usual rates at the same time.

Measured recoveries of fertiliser N in crop and soil (0–23 cm) were uniformly high, being between 78 and 84% (Table 3). True recoveries in crop and soil must have been even higher, as some labelled N would have been present in the soil at depths greater than 23 cm. Recoveries of fertiliser N in grain increased from 41 to 54% as fertiliser N applications increased and then decreased with the largest application.

A remarkable feature of the results is the increase in uptake of unlabelled soil N as labelled fertiliser application increased. More than twice as much soil N was taken up by

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TABLE 3

Uptake of N from fertiliser and from soil by winter wheat growing on Broadbalk

Addition of ^{15}N labelled fertiliser (kg ha^{-1})	Uptake of N, in grain straw, chaff and stubble (kg ha^{-1})		Fertiliser N remaining in soil (0–23 cm) (kg ha^{-1})	Recovery of fertiliser N in plant and soil (%)
	From fertiliser	From soil		
0	0	29·7	0	0
47·3	23·5	39·1	15·8	83·1
94·4	59·1	60·3	17·2	80·8
141·0	94·6	72·9	24·6	84·5
181·6	117·6	73·3	25·0	78·5

the wheat receiving 182 kg labelled fertiliser N as by the wheat receiving none. This increase is greater than the total amount of fertiliser N found in the top 23 cm of soil, so that isotopic exchange or immobilisation/mineralisation cycling cannot be the sole explanation, and at least two other factors must be involved. Firstly, the quantity of inorganic N remaining deep in the profile from previous seasons is greater where more (unlabelled) fertiliser was applied in the past. Secondly, there is independent evidence that plots on Broadbalk receiving inorganic N annually contain more biomass than plots receiving no N, and therefore presumably mineralise more N each year. (Jenkinson, Johnston, Powlson, Pruden and Williams)

Urease inhibitors. Rapid hydrolysis of urea fertiliser applied to soils results in high ammonium and pH levels which may be detrimental to a crop, and some of the fertiliser nitrogen may be lost from the soil by volatilisation of ammonia. Quinones can reduce the rate of urea hydrolysis in soils, and their efficacy has been tested in small field trials by comparing hydrolysis rates of injected aqueous urea with or without an inhibitor. Hydroquinone (3·8 kg ha^{-1}) had no effect on hydrolysis when injected with 100 kg ha^{-1} urea N under winter wheat in autumn 1979, or when injected at 1·5 kg ha^{-1} with 375 kg ha^{-1} urea N under a grass ley in early spring 1979. 2,6-Dimethylbenzoquinone (1·5 kg ha^{-1}) injected under grass with 375 kg ha^{-1} urea N in early or late spring 1979 increased the time for complete hydrolysis from 9 to 13 days. Benzoquinone (5 kg ha^{-1}) injected with 375 kg ha^{-1} urea N under a grass ley in late autumn 1979 similarly increased the time for complete hydrolysis from 15 to 22 days. The quinones tested are unlikely to be practical urease inhibitors, but 2,6-dimethylbenzoquinone was an effective nitrification inhibitor, comparable to nitrapyrin in its efficacy. (Rodgers, Widdowson and Penny)

Inhibition of nitrification and urea hydrolysis by CS_2 derivatives. Three carbon disulphide derivatives are approved farm chemicals: the fungicide thiram and the herbicides dimexan and 'EXD' (the diethyl analogue of dimexan). Urease and nitrification inhibition by these materials (previously reported only for thiram) and by hydroquinone and nitrapyrin respectively, as standards of comparison, were measured by incubating (at 24°C) soil treated with a kaolinite/inhibitor mixture, supplying various concentrations of inhibitor, and an aqueous solution of urea or NH_4HCO_3. This method of applying the inhibitor avoided the possible complications of solvents or emulsifiers. The results of analysing KCl extracts of the soil after 3 days or 3 weeks respectively can be used to express inhibition on a percentage basis (Table 4) and show that dimexan in particular is a potent inhibitor of urease and nitrification. (Ashworth)

Nitrification inhibitors with aqueous urea for grassland. Nitrapyrin is now used by contractors in the UK to try to restrict losses of nitrate during winter after injecting aqueous ammonia. Nitrapyrin was injected with aqueous urea, and its effects compared

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TABLE 4

Urease and nitrification inhibition (%)

(a) Urease inhibition after 3 days

Inhibitor (mg kg^{-1} moist soil)	10	50	100
Hydroquinone	31	61	69
Thiram	13	40	55
Dimexan	23	72	80
'EXD'	12	37	44

(b) Nitrification inhibition after 3 weeks

Inhibitor (mg kg^{-1} moist soil)	1	10	25
Nitrapyrin	78	95	95
Thiram	15	20	48
Dimexan	58	90	97
'EXD'	14	83	94

with those of sodium trithiocarbonate, potassium ethyl xanthate and the herbicide 'EXD' on growth of a ryegrass ley at Rothamsted. When applied in November, all the materials improved the recovery of the injected urea in 1979 and 1980 and in 1980 improved total dry matter production also.

When applied with urea in spring, the inhibitors had little effect on yield or N recovery in either year. However, in 1979 these inhibitors improved yields and N recovery from aqueous urea plus ammonium nitrate injected in spring, as previously found with aqueous ammonia (Ashworth *et al. Journal of the Science of Food and Agriculture* (1980) **31**, 229–237). These results are tentatively attributed to the effects of ammonium nutrition. The value to ryegrass of various ratios of ammonium and nitrate in soil solution is being investigated in pot experiments. (Rodgers, Widdowson, Penny and Ashworth)

Nitrate leaching in cropped soil during winter. In 1978 and 1979 nitrate and chloride were applied simultaneously at the beginning of November to plots in the field: the profiles of these ions in soil throughout winter differed little. About 60% more of the applied nitrate remained above 1 m depth on 26 February 1980 than on 28 February 1979, and nearly four times as much nitrate remained above 60 cm, despite the relatively small (25 mm) difference in the rainfall between application and the February sampling in the 2 years. The simpler computer model for nitrate leaching in aggregated soils (*Rothamsted Report for 1976*, Part 1, 87) simulated all the profiles of both ions reasonably successfully.

Nitrate and chloride profiles under plots growing winter wheat or winter rye did not differ significantly from under plots left bare. Spring barley was sown on the bare plots, and apparent recoveries of nitrate and chloride at anthesis measured (from the difference between treated and control plots). In 1979 crops recovered less than 10% of the applied nitrate, but in 1980 winter wheat recovered 37% and spring barley 32% of the nitrate, the difference probably being due to the leaching pattern. Both crops recovered a greater percentage of the applied nitrate and chloride with 115 than with 57·5 kg N ha^{-1} in 1980. (Addiscott)

Prediction of nitrogen requirement for winter wheat. A major effort is now being made to understand the nitrogen economy of winter wheat in detail. The most important practical outcome would be a method of predicting the best amount of N fertiliser to apply to individual fields, and the nitrate leaching model is being developed as part of a system for predicting the amount of nitrogen required as a spring top-dressing. Mineralisation of soil organic nitrogen and nitrification of ammonium N are treated

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by empirical relationships derived from laboratory experiments, with the effects of temperature given by 'pseudo-Arrhenius' relationships. Initial comparisons with field data from the Yield Variation experiments (p. 245) show that the system predicts reasonably well the total amount of nitrogen in the profile and the depth of the peak nitrate concentration in the spring, but does not yet give satisfactory ratios of ammonium to nitrate in individual layers. (Addiscott)

Grain nitrogen concentration and nitrogen fertiliser rate. Results from 20 years of wheat experiments were used to compare responses of grain N% and grain yield to increasing amounts of fertiliser nitrogen. Grain N% for both winter and spring wheat increased, mostly linearly, throughout the range, whereas many of the grain yield curves reached a maximum and then declined with further additions of nitrogen (*Rothamsted Report for 1978*, Part 1, 282). Provided curve sections exhibiting dilution effects were excluded, the linear or near-linear relationship between grain N% and fertiliser N allowed linear regression models to be fitted. This showed that, over a range of 50–175 kg N ha^{-1}, an average of 32 kg ha^{-1} of fertiliser nitrogen was required for an increase of 0·1% N in grain dry matter of winter wheat or 56 kg N ha^{-1} for an increase of 1% protein. Results from 3 years of experiments conducted by the Agricultural Development and Advisory Service (ADAS) agreed closely with those from Rothamsted.

Using the linear relationship between grain N% and fertiliser N, curves were plotted of grain yield against grain N%, adjusted for comparable additions of fertiliser N (75, 100, 125, 150 kg ha^{-1}). The curves tended to have sections with rising yield for small applications of N, to exhibit a maximum in a central zone and descending sections for large applications. There was however no well-defined 'critical level' of %N, beyond which grain yield was inversely related to grain N%. (Benzian, with Lane, Statistics Department)

Nitrogen concentration and phosphorus fertilising. At Saxmundham yields of winter wheat, and %N in grain, increased both with the amounts of nitrogen applied (40–160 kg N ha^{-1}) and the amounts of $NaHCO_3$-soluble P in the soil (5·5–35·5 mg P kg^{-1} soil). When plotted to show relationships between grain yield and %N in grain, the results, for all rates of fertiliser N applied, lay on separate lines corresponding to different levels of soil P. Increasing amounts of $NaHCO_3$-soluble P in the soils increased yields but slightly decreased %N in the grain (Table 5). (Johnston and Poulton)

TABLE 5

Winter wheat %N in grain

N applied (kg ha^{-1})	Bicarbonate soluble P mg kg^{-1}: 5·5		9·1		16·7		23·1		28·2		35·5	
	Yield	%N	Yield	%N	Yield	%N	Yield	%N	Yield	%N	Yield	%N
40	3·99	1·67	4·77	1·50	4·67	1·65	4·97	1·59	5·47	1·57	5·10	1·57
80	4·77	1·92	5·63	1·71	5·97	1·82	6·06	1·79	6·18	1·79	6·75	1·79
120	4·80	2·11	6·73	1·93	6·73	1·92	7·29	1·92	7·17	1·92	7·29	1·83
160	5·32	2·06	7·40	1·99	6·90	2·03	8·04	2·04	7·79	2·02	8·09	1·99

Investigations on phosphorus and potassium

Heterogeneity of cation exchange sites in soils. Potassium–calcium exchange equilibria were investigated on untreated and potassium-fertiliser treated soils from long-term experiments at Rothamsted, Saxmundham and four ADAS Experimental Husbandry Farms. Groups of homogeneous cation exchange sites were identified by plotting the

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differential enthalpy of exchange [$d(\Delta H_x)/dx$] against fractional K saturation (x). These resembled groups of sites found in five 'standard' clay minerals (*Rothamsted Report for 1976*, Part 1, 230). In particular, the $d(\Delta H_x)/dx{:}x$ plot for a Worcester series soil from Brackenhurst EHF, containing 60–70% mica, was identical to that of muscovite mica. More complex $d(\Delta H_x)/dx{:}x$ plots were obtained with the other soils, most probably caused by differences in clay/silt mineralogy, degrees of interstratification and organic matter or mineral coatings. The determination of such ion exchange properties may improve the identification of aluminosilicates in soils.

A comparison of plots of activity coefficients of adsorbed K, f_K, against x with $d(\Delta H_x)/dx{:}x$ plots for the soils and clays, confirmed that the degree of variation of f_K with x reflected heterogeneity of exchange sites and was related to soil mineralogy. In particular, maxima in $f_K{:}x$ occurred at K saturations at which strong K adsorption sites were filled and adsorption began on 'planar' sites. Because there is not a sharp distinction between exchangeable and non-exchangeable K, the values of f_K as $x \rightarrow 0$ indicate how strongly the intermediate K is held, and how easily this first part of the non-exchangeable K may be released.

Residual K from long-term K application to field soils decreased K binding strength and caused some realignment of 2:1 aluminosilicate layers, shown by the less negative standard and differential entropy values of the Ca→K reaction. K preference decreased with increasing amounts of added K and time of reaction between soil and K fertiliser, and with decreasing '2:1 layer' mineral content of the soil. (Goulding and Talibudeen)

Natural radioactivity measurements in soil for assaying potassium reserves and fertiliser residues. Earlier measurements of radioactive isotopes in soils (Talibudeen, *Soils and Fertilizers* (1964), **27**, 347–359, and Talibudeen & Yamada, *Journal of Soil Science* (1966), **17**, 107–120) have been refined and their precision improved using solid state nucleonics with better long-term stability (*Rothamsted Report for 1978*, Part 1, 297). Changes in total K and in ^{124}Bi from the uranium–radium series, in soils from the Classical Experiments, were related to fertilisers applied over several years. (Smith and Talibudeen)

Effects of mycorrhizas on plant growth and internal P concentration in the field. Effects of vesicular-arbuscular mycorrhizal infection on the growth of spring wheat (cv. Highbury) were tested at four levels of soil P. There were four treatments: natural soil and fumigated soil (methyl bromide) both with and without added inoculum (*Glomus mosseae*). Fumigation virtually eliminated natural infection and had no obvious toxic effects on the wheat. Effects of added inoculum on dry matter production were slight and non-significant, though mycorrhizal infection was increased, and added P greatly increased growth. However, on fumigated soils infection increased the %P in shoots more than any level of P fertilisation did, an example of a general effect previously noted in pot experiments only (*Rothamsted Report for 1979*, Part 1, 229). Surprisingly, inoculation led to a two- to four-fold increase in Br uptake on all plots. (Buwalda, Stribley and Tinker)

In an experiment on potatoes, artificial inoculation failed to increase the (very low) mycorrhizal infection, %P in leaf tissue, or tuber yield. In pot experiments, potato plants become heavily infected on unsterile soil only if grown from true seed or from small fragments of tuber bearing a bud instead of whole tubers. This suggests that the usual practice of growing potatoes from large propagules militates against mycorrhizal infection. (Stribley)

Use of host photosynthate by fungus. The hypothesis that enhanced C loss from mycorrhizal plants is responsible for the disproportionately high concentrations of their internal

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P (Stribley, Tinker & Rayner, *New Phytologist* (1980), **86**, 261–266) has been studied using leek plants pulse-fed with $^{14}CO_2$. About 5% more of carbon assimilated by infected plants was diverted to the root system, as compared to equivalent non-mycorrhizal plants, 48 h after $^{14}CO_2$ feeding. Below-ground liberation of CO_2 by respiration of mycorrhizal plants used 3% more. (Snellgrove and Tinker)

Models of infection spread with a developing root system. Two models previously proposed (*Rothamsted Report for 1979*, Part 1, 229) did not fit data from a pot experiment on wheat, in which root densities were manipulated by growing different numbers of plants per pot. Instead, a good fit was obtained with a model based on the assumption that the rate of increase of length of root infected is proportional to the product of the length of infected root at a given time, and the proportion of the total root length still susceptible to infection at that time (the logistic growth curve). (Buwalda, Tinker and Stribley, with Ross, Statistics Department)

Organic matter

Effects on organic matter on soils at Woburn. Debate on the value of organic matter for the fertility of light soils has continued for many years, but is not yet resolved. We summarise here the most recent work on the long-term trials at Woburn (see *Rothamsted Report for 1973*, Part 2, 98–151; *Rothamsted Report for 1974*, Part 1, 85–87) which received organic matter in various forms between 1965 and 1970.

During the period 1972–76 the test crops were potatoes, winter wheat, sugar beet, spring barley and winter oats. Total additions of nutrients were 450 kg P ha^{-1}, 850 kg K ha^{-1} and 120 kg Mg ha^{-1}. Changes in the composition of the surface soil since 1971 were small for both K and Mg (ADAS Index 2 and 1 respectively) because cations were leached below plough depth, but the soil is now in ADAS Index 5 for P.

Between 1971 and 1978–79 all treatments which had carried leys or received organics lost some organic carbon, but still contained more organic carbon than the rest of the plots in 1979. Added organic matter mainly influences crop growth by releasing nitrogen or by amending soil structure and thereby increasing available water in the soil. It is likely that the extra N supply was most important when no fertiliser N was given; on this assumption, a minimum estimate of the effective amounts of nitrogen released in this period were calculated from response curves relating total dry matter produced and the cumulative N dressings applied to crops grown without organics. These amounts were: residues from leys with clover, 170 kg N ha^{-1}; from leys given nitrogen, 200 kg N ha^{-1}; from peat, 0 kg N ha^{-1}: from straw, 50 kg N ha^{-1}; from green manuring, 80 kg N ha^{-1} and from farmyard manure, 140 kg N ha^{-1}.

Residues from organics applied between 1965 and 1971 increased maximum yields of the crops grown from 1972 to 1976, and a second rotation of test crops was grown, with potatoes in 1977–78 and winter wheat in 1978–79, to determine how long these benefits persist. Eight rates of inorganic N were applied to subplots of the experiment for each crop (except winter oats) so that yields from all treatments could be compared in the presence of the optimum amount of N.

The extra crop yields from residues of farmyard manure or leys, averaged over the four largest nitrogen dressings (which gave similar yields) were; for farmyard manure: potatoes, 5·2 t ha^{-1} and wheat, 0·66 t ha^{-1}; for leys: potatoes, 12·5 t ha^{-1} and wheat, 0·53 t ha^{-1}. Thus organic residues added to a soil with 0·7% C increased crop yields for 6–8 years after their application. Long leys (7–8 years) were more effective than large dressings of farmyard manure (250 t ha^{-1}) or residues from straw (45 t dry matter ha^{-1}). Benefits from peat (45 t dry matter ha^{-1}) were small for crops given little nitrogen but

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much larger at higher rates of nitrogen. The effects of previous manuring with trefoil and red clover between 1965 and 1971 lasted only 3–4 years. Extensive crop and soil monitoring to determine the causes of the yield responses with certainty is planned for the next phase of the experiment. (Mattingly, Chater, Poulton and Emerson).

Measurement of soil biomass phosphorus. The amount of phosphate (both organic and inorganic) that can be extracted from soil by 0·5M-$NaHCO_3$ (pH 8·5) is increased by fumigation of soil with $CHCl_3$. Previous work (Jenkinson & Powlson, *Soil Biology and Biochemistry* (1976) **8**, 167–177) has shown that the extra *carbon* made decomposable by $CHCl_3$ comes entirely from the microbial biomass and can be used as a measure of the biomass carbon content of the soil. It is therefore likely that the additional P made extractable by $CHCl_3$ also comes from the biomass and may give a measure of soil biomass P.

Increasing the fumigation time of an old grassland soil to 4 h caused progressive increase in extractable P, but longer exposure caused no further P release. The proportion of the released P that was inorganic varied between soils and was increased by the time of exposure to $CHCl_3$, so that when this was over 4 h, 85–95% was inorganic.

After being released by $CHCl_3$, P can be sorbed by soil particles. It is possible to correct for sorption of inorganic phosphate (but not organic P) by measuring the recovery of P from a known addition of phosphate. The greater the proportion of inorganic P in the $CHCl_3$-released P, the more dependable will this correction be, so we now use a 24 h $CHCl_3$ fumigation. $CHCl_3$ had no effect on the extractability of native soil inorganic P, so the extra inorganic P measured after prolonged fumigation is derived from organic P, presumably by enzymic hydrolysis.

Biomass C and P released by $CHCl_3$ were measured in five unamended soils, and in one which had been amended with either glucose or straw to increase soil biomass. The amount of P made extractable by $CHCl_3$ was closely related to biomass C in these soils.

When lyophilised laboratory-grown microorganisms were added to soil, and then subjected to $CHCl_3$ fumigation and $NaHCO_3$ extraction, about 40% of the P in the organisms was recovered in the $NaHCO_3$ extract. Further work is in progress to see if native soil organisms behave similarly. Applying this figure to the quantities of P released by $CHCl_3$ from arable and grassland soils gives biomass P values of between 5 and 35 kg ha^{-1} in the top 10 cm of soil. These values are equal to, or with the old grassland soil, considerably greater than, the annual P uptake of the crop. (Brookes, Powlson and Jenkinson)

Decomposition of ^{14}C labelled plant material. Measurements of the rate of decay of plant material under tropical conditions (Jenkinson & Ayanaba, *Soil Science Society of America Journal* (1977) **41**, 912–915) have been concluded. Decomposition of labelled maize leaves was initially slower in experiments started at the beginning of the dry season than at the beginning of the wet season, but there was little difference after 1 year. Decomposition was initially slower in a strongly acid oxisol than in a near-neutral soil but again there was little difference after 1 year. Eight per cent of the carbon originally added as labelled ryegrass still remained in the soil after 5 years incubation in tropical rain forest. These results are being used in modelling the influence of climate on the turnover of organic matter in soil. (Jenkinson, with Dr A. Ayanaba, International Institute of Tropical Agriculture)

Ryegrass uniformly labelled with ^{14}C was incubated aerobically at 25°C for 62 days in two contrasting soils, a near-neutral (pH 6·8) Paleudalf from England and a strongly acid (pH 3·6) Haplorthox from Brazil. In neither soil did the addition of fresh plant

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material significantly accelerate the evolution of CO_2 from organic matter already in the soil, i.e. there was no priming action.

In the near-neutral soil labelled plant material decomposed rapidly, and there was a rapid build up of labelled microbial biomass in the first 6 days, followed by a much slower increase that continued throughout the whole incubation period. After 62 days 22·5% of the labelled C remaining in the near-neutral soil was in the biomass. Decomposition was slower, and much less labelled microbial biomass was formed in the acid soil, and after 62 days only 6·2% of the labelled carbon remaining was in the biomass. (Cerri and Jenkinson)

Micronutrients and heavy metals

Metal toxicity to plants. The possible toxic effects of heavy metals in sewage sludge applied to agricultural land have been investigated. Oats were grown in soil treated with either inorganic metal salts, or sludge prepared by anaerobic digestion of raw sewage in the presence of metals, plus extra controls with additions of sludge digested without added metals. Root yields were not significantly affected by additions of untreated sludge or Cr-treated sludge, but Zn-treated sludge or to a lesser extent Cu-treated sludge caused some significant growth depressions. Cr-treated sludge stimulated shoot growth, but Cu-treated sludge had no effect. Metals added as inorganic salts again had greater effects on roots than on shoot yields. Zn at more than 400 $\mu g\ g^{-1}$, Cu at more than 100 $\mu g\ g^{-1}$ and Ni at more than 100 $\mu g\ g^{-1}$ decreased root growth. Shoot yield was decreased by addition of more than 200 $\mu g\ g^{-1}$ Cu and 100 $\mu g\ g^{-1}$ Ni, but not by Zn at up to 400 $\mu g\ g^{-1}$. Chromium had no significant effect on root or shoot yields at up to 400 $\mu g\ g^{-1}$.

Zinc is thus more toxic than copper after digestion in sludge, but less so when applied as inorganic salts; the latter agrees with the 'zinc equivalent' index of metal toxicity used by ADAS and Department of the Environment (DOE). The strong complexing of copper by organic compounds explains the different results with metals in sludge, which need to be taken into account in assessing their toxicity.

Under most soil conditions, chromium of valency 3 (Cr(III)) is precipitated (*Rothamsted Report for 1979*, Part 1, 231–232) and it is not thought to be as toxic to plants as Cr(VI). In flowing nutrient solution at pH 4·5 Cr(III) does not precipitate, and both Cr(III) and Cr(VI) were taken up by and were toxic to oats. In soils Cr(VI) may be reduced to Cr(III) at low pH, and under these conditions Cr(III) may possibly be toxic. (McGrath)

Concentrations of copper and manganese in displaced soil solutions as a function of pH. Six air-dried sandy loam soils with pH values between 5·0 and 7·5 were incubated for 4 or 8 weeks after wetting with water or 0·01M-calcium chloride. The soil solutions were collected by displacement, and total copper and cupric ions were determined in them using flameless atomic absorption spectrometry and a cupric ion-selective electrode respectively.

The concentrations of copper in solution were fairly constant with pH but the cupric ion concentrations varied considerably. The copper and organic carbon concentrations in solutions from $CaCl_2$-incubated soils were considerably smaller than where water only was used, and the proportion of copper present as cupric ion at a given pH considerably larger. They suggest that complex formation with organic matter is a principal mechanism for keeping copper in solutions at high pH values, and that calcium ions are able to compete with cupric ions in complex formation.

Manganese and manganous ions were determined in similar displaced soil solutions. The concentration of manganese varied very greatly with pH and in every case over 50% of the manganese in solution was present as manganous ions.

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In related studies, the equilibrium between cupric ions, bound copper species in solution and copper adsorbed on soil surfaces was studied by determining copper adsorption isotherms at low concentrations on (i) each of the soils described above at its natural pH in $CaCl_2$ and (ii) the most acid of these soils at a series of pH values. At a given copper concentration the quantity of copper adsorbed increased, and the proportion of copper in solution present as cupric ion decreased with an increase in pH. Differences in the behaviour of the soils were much more due to the different pH at which measurements were made than to intrinsic differences between them. (Sanders)

Soil structure

The interaction of water with soils and clays. Volume changes within the soil are important in the development of soil structure. They depend on the amount and type of clay present and hence on the total specific surface of a soil. A reliable means of measuring the total specific surface can therefore help to understand the process of structure formation.

Total specific surface is usually measured by the sorption of ethylene glycol or ethylene glycol monoethylether, both of which have disadvantages. Water itself has several potential advantages as a sorbate for studying the surface of soil, but problems arise because a water monolayer on montmorillonite is shared between two internal surfaces for relative vapour pressures (p/p_0) between 0 and 0·35. It is known, however, from X-ray diffraction measurements that Ca-saturated expanding layer silicates form an interlamellar complex consisting of two monolayers of water, one on each internal surface, over humidities ranging from 0·3 to 0·7. So it should be possible to establish an effective monolayer by equilibration at a humidity in this range, and then simply estimate the total specific surface from the weight of water sorbed.

This hypothesis was tested for 63 soils containing more than $40\% < 2\ \mu m$ clay, representing a wide range of clay minerals. There was a high degree of linear correlation ($r=0·96$) between water sorbed at $p/p_0=0·5$ (pF 6) and ethylene glycol sorption. However, because internal and external surfaces have water layers of different thickness, it is important to be able to distinguish between these surfaces and this is being attempted by making measurements at different p/p_0 values. (Newman)

Alternatively it might be possible to distinguish external surfaces from internal ones more directly. Using X-ray diffraction, interlamellar volume might be measured as a function of relative humidity, and then by using data on standard clay minerals to calculate the density of interlamellar water, the total water sorbed could be corrected for interlamellar sorption. Little data exist, however, for the mixed layer and disordered clay minerals commonly found in British soils. We have therefore begun to measure sorption and interlayer spacing over a range of humidities, using fine, medium and coarse clay fractions ($<0·04\ \mu m$. 0·04–0·2 μm and 0·2–2 μm) of 12 British soils whose mineralogy represents a range of mixed layer components. Desorption and sorption isotherms are being measured using saturated salt solutions to control relative humidity. A similar control will be used on a diffractometer with a modified sample chamber, so that the basal spacings can be recorded over the same range of humidities. In this way we hope to gain further insight into the effect of mineral composition on soil structure, through its effects on water relationships. (Ormerod and Newman)

Soil structure formation. The regeneration of soil structure after damage is being investigated. In the first experiment on Pastures Field, Rothamsted (Batcombe series soil) (*Rothamsted Report for 1979*, Part 1, 235), the soil structure was damaged by heavy wheeling in April 1979 and then allowed to regenerate naturally with no further traffic.

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The plot was harvested and resown by hand with winter oats, and raked lightly. Plant establishment was initially poor, but by May 1980 plant growth was equally satisfactory on the old wheeled and unwheeled areas; fresh wheelings made in March 1980, however, had severely stunted growth. Surface profiles of the wheeled areas were almost unchanged between first treatment in April 1979 and harvest in 1980, but the whole soil surface rose and fell in response to changes in soil water content. Differences in water release characteristics ($-0{\cdot}05$ to -15 bar range) were small, though mercury porosimetry tended to confirm that wheeling slightly decreased the volume of pores in the size range 1–100 μm, but increased porosity in the range 6–100 nm. Impregnated soil sections showed clearly, however, that in the wheeled soil voids larger than 60 μm increased substantially, particularly during the summer of 1979, when large fluctuations of soil water content occurred. Wetting and drying quickly opened up horizontally planar voids within 4 cm of the soil surface, and by April 1980 the process had extended below 6 cm depth. The unwheeled samples by contrast contained a larger proportion of irregularly shaped voids throughout. Surface profile and clod density measurements showed that relatively little change occurred between April and August 1980 and suggested that little further improvement in soil aeration could be expected. The project will be extended to other soil types in 1981. (Newman, with Bullock, Murphy and Thomasson, Soil Survey)

Effects of subsoiling on soil structure. A section on porosity and water content measurements made for this experiment is included in the Multidisciplinary Activities section (p. 26). (Newman)

Solute movement in soil

Simulation of herbicide movement. The nitrate leaching model has been adapted for adsorbed solutes, and was used to simulate the movement of the herbicide fluometuron in an aggregated soil of the Denchworth series. The simulation obtained was rather better than that from a much more complex model (Leistra, Bromilow & Boesten, *Pesticide Science*, (1980), **11**, 379–388). (Addiscott, with Nicholls, Insecticides and Fungicides Department)

Soil and clay mineralogy

Mineralogy of palaeosols from the Lower Carboniferous in South Wales. A study of palaeosols can provide information about the geomorphic and climatic conditions that prevailed when the soils were formed. The clay mineralogy of three paleosol complexes in South Wales (Wright, *Naturwissenschaften* (1980), **67**, 252–253) was investigated, to supplement the morphological evidence of the climatic conditions under which they were formed.

The mineralogy of the two lower palaeosols and the lower horizons of the upper palaeosol consists dominantly of mixed layer, near fully ordered illite–smectite with small amounts of illite, chlorite and quartz. The clay from the uppermost horizon of the upper palaeosol consists of a mixture of similar illite–smectite and a dioctahedral chlorite. The horizon 1 m below this contains an interstratified kaolin–smectite or kaolin–illite–smectite.

Fully ordered illite–smectites do not usually occur in soil, and their presence in these clays suggests that the original minerals in the palaeosols may have been altered after the soils were buried and exposed to high temperatures and pressures. The possibility that the minerals in the palaeosols have been subjected to post-burial diagenesis complicates the use of the mineralogical data as indicators of the conditions in which the soils developed. (Brown and Dr V. P. Wright, Department of Geology, University College, Cardiff)

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Soil origin and distribution

Spatial analysis of soil properties. Research on the application of regionalised variable theory to spatial variation in soil has continued, but with emphasis changing towards soil fertility mapping, explanation of variation in crop yield and trace element survey.

Measurements of exchangeable potassium (K), available phosphorus (P) and pH of topsoil made in the initial survey of Broom's Barn Experimental Station were analysed. Spatial dependence extended to between 200 and 300 m, and for K and P there was substantial variation within the shortest sampling interval, 40 m, which appears in the analysis as 'nugget' variance. Variation in pH was unusual in that the nugget variance was almost nil. Using these results the three properties were interpolated optimally and isarithmic ('contour') maps drawn of them automatically.

Data on the copper and cobalt contents of topsoil over 3000 km^2 in south-east Scotland, obtained in a survey carried out by the East of Scotland College of Agriculture have been analysed similarly. The pattern of variation in these elements is more complex than we have encountered for smaller areas, and suggests that there are contributions to the variance for quite different scales of distance.

Spatial variation in field crops has been studied by re-analysing some of the early uniformity trials. All show spatial dependence but with varying degrees of anisotropy. The classical trial on wheat carried out by Mercer and Hall at Rothamsted in 1910 proved especially interesting in that variation was periodic. The periodicity, apparent only in the east-west dimension, was almost certainly not caused by the cultivation regime at the time but by an earlier ridge and furrow pattern with ridges running from north to south.

Research on the procedures themselves has led to the development of a general sampling strategy. Thus, given a functional expression that relates variance of the property of interest to separating distance and direction a sampling scheme can be designed to provide estimates of given precision for blocks of land or crop of any size and rectangular shape. (Webster and McBratney)

Origin and distribution of brickearths in south Hampshire. Field survey, mainly in the New Forest area, has shown that brickearth $>0{\cdot}2$ m thick is much more extensive than indicated on the maps of the Institute of Geological Sciences. It mantles almost all of the terraced gravels in the area and is thickest (up to 2 m) on wide terrace surfaces, but is thin or absent on narrow ridged terrace fragments that are more subject to erosion. Some valley bottoms have colluvial brickearths overlying brown earth soils, suggesting that part of this erosion has occurred during the Post-Glacial period. The brickearths consist mainly of coarse silt and fine sand particles and are thus probably aeolian.

On several terraces discontinuous palaeo-argillic horizons lie between the brickearth and the gravels. These previously unrecorded horizons represent soil development during a period or periods after the deposition of the gravels but prior to that of the brickearth. (Reynolds and Weir)

Elemental sulphur in plastic drainage pipes. The Field Drainage Experimental Unit, Cambridge (FDEU), has an experiment on Sedgemoor in Somerset, in which the entrance slots in the drainage pipes became blocked, and a laboratory study was made to find the optimum slot width. Horizontal sections of pipe were inserted through soil cores of 85 cm diameter which were then irrigated with rainwater for 2–3 months. A pale grey material formed on the inside of the pipes consisted of a mixture of peat and pale grey flaky material. The X-ray powder diffraction pattern of the latter contained only reflections corresponding to rhombic sulphur and gave the mass spectrum of sulphur.

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The source of the sulphur seems to be gypsum in the Keuper Marl. The sulphate drains into the peat, and is reduced to sulphide in the anaerobic zones. At the surface between the anaerobic peat and the aerobic anterior of the pipe sulphide is reoxidised to elemental sulphur. Normally elemental sulphur in soils is thought to occur only as a transient intermediate, but the persistence of elemental sulphur at the soil–air interface in the drainpipes may be explained by rapid oxidation there, or possibly by the lack of Fe^{3+} ions which are normally present with sulphur derived from pyrites. Similar whitish deposits have been observed in the ditches at the outfalls of the drains on Sedgemoor and it is hoped to confirm that this is also rhombic sulphur. (Brown and Dr C. W. Dennis, FDEU)

Mineralogy and weathering of the Shirdley Hill Sand. This wind-blown sand covers approximately 200 km² of south-west Lancashire, and is the parent material of argillic brown earths and podzolic soils that are under intensive arable rotation, and whose leached E horizons are used for glassmaking. Generally it is <1 m thick, and disturbed throughout.

Analyses of 30 samples showed that the particle size distribution of the Shirdley Hill Sand is everywhere unimodal and moderately well sorted. This suggests that the sand was blown by gentle multidirectional winds from a local source. None of 40 samples of several other local sands analysed has the same particle size characteristics. All are either finer or coarser, and all except the fluvioglacial sands and Triassic sandstones are much better sorted.

Principal coordinate analysis and a minimum spanning tree of the heavy mineral suites in the fine sand divided the 70 samples into three main groups: (a) fluvioglacial sands and all but four of the Shirdley Hill sands, (b) Triassic and Carboniferous sandstones and four remaining Shirdley Hill sands, (c) beach, dune, inland blown and Irish Sea sands. The original, unweathered Shirdley Hill Sand strongly resembles the fluvioglacial sand, but subsequent weathering has depleted the heavy mineral suite so that in surface layers it resembles that of the sandstones.

We suggest that during Zone III of the Late Devensian the fluvioglacial sands were repeatedly reworked by the wind. Their coarser particles were redeposited nearby as periglacial coversand, the Shirdley Hill Sand, but finer sand particles were progressively removed from the area. (Catt and Bateman, with Dr P. Wilson, Manchester University)

Protein extraction

With sunflower, fat hen, beans, *Atriplex*, lucerne and amaranth, maturity affects the pH of leaf pulp, and the dry matter and tannin content of the leaves and the robustness of their cells. Changes in the extractability of protein as leaves age are usually the net result of several of these factors changing simultaneously, with no single factor having an over-riding effect.

Minor improvements have been made to various aspects of the leaf juice extractor. Nevertheless, it is clear that it should still be possible to get pulp to move more efficiently into the section of the unit in which it is pressed. Several different arrangements await trial when a variety of crops becomes available in spring.

In many countries, the β carotene in leaf protein will be as important nutritionally as the protein. Measurements are therefore being made of the stability of β carotene in moist leaf protein, preserved with acetic acid or salt, when kept in the dark at room temperature with restricted access of air.

The first two numbers of '*Leaf Protein Newsletter*', with abstracts of relevant papers

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in the last 2 years, have been compiled. More will appear from time to time. (Butler and Pirie)

Methods, apparatus and techniques

Preparation line for conversion of NH_4-N to N_2 for isotope ratio determination. The gas preparation line supplied with the Micromass 602D mass spectrometer was unsatisfactory and a new all-metal line was designed. Samples containing about 1000 μg N are preferred, although the procedure can handle from 25 to 2000 μg N. When an enriched sample containing 1 atom % excess ^{15}N was put through the whole procedure from digestion to measurement, and then followed by a sample at natural abundance, memory effects were less than 1 part in 10 000. (Jenkinson, Pruden and Powlson)

Gravimetric determination of mean temperature. A gravimetric method for measuring mean temperature (Ashworth, *Journal of Applied Ecology* (1980), **17**, 227–233) by hydrolysis of potassium ethyl xanthate was compared with data from thermistors on the intensively monitored site on Little Knott field. After one week, nickel sulphate was added to stop the hydrolysis of the xanthate, and the dry weight of precipitate was converted, by means of a calibration curve, to an effective mean temperature for the week. These results agreed with the arithmetic mean temperature within $0{\cdot}3 \pm 0{\cdot}2$°C over a 12-week period. (Ashworth with North and Cuminetti, Physics Department)

Analytical Section

Analyses. 89 000 digestions and analyses were done this year, 6·7% less than last year; 10·5% of the total were for other departments. (Avery, Cosimini, Messer and Pope)

The estimation of dicyandiamide in soils (Vilsmeier, *Zeitschrift für Pflanzenernährung und Bodenkunde* (1979), **142**, 792–798) has been adapted using the Technicon Auto-Analyzer. (Messer and Rodgers)

Staff and visiting workers

C. Bloomfield retired in September after 34 years at Rothamsted, and R. J. Avery resigned in May.

N. W. Pirie spent 2 weeks in India during April to see progress of work on leaf protein, partly financed by the Royal Society, and attended a COSTED meeting in Paris, financed by ICSU. P. B. Tinker was invited to Brazil in March to speak at the Symposium on Root/Soil System, sponsored by CNPq (Brazilian National Research Council), in July he visited five German research institutes on a Royal Society travel grant and in September, at the invitation of the University of Saskatchewan, he visited various centres in USA and Canada, lecturing and examining. G. E. G. Mattingly visited the Indian Agricultural Research Institute in Delhi in February to discuss collaboration in research projects with Indian Soil scientists, by arrangement with the Ministry of Overseas Development. T. M. Addiscott was invited to give a paper at the ITAL/SCOPE workshop at Wageningen in January and also at the IIASA meeting at Laxenburg, Austria, in June; J. H. Rayner acted as chairman at the former meeting. On return from secondment in Edmonton, J. Ashworth visited Australia where he lectured at Monash University, the University of Queensland and at the Wheat Research Institute, Toowoomba. In July he visited the Lehrstuhl für Pflanzenernährung at Weihenstephan, West Germany, at the invitation of SKW Trostberg AG to discuss the use of dicyandiamide as a nitrification inhibitor. A. E. Johnston visited Holland in June and October, sponsored by EEC, to present papers at seminars on soil degradation and on phosphorus in sewage sludge and animal

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waste. A. C. D. Newman, sponsored by ARC, and A. H. Weir, sponsored by the Mineralogical Society of Great Britain, attended the Fourth European Conference on Clay Minerals in Germany in September, and F. V. Widdowson visited France in June to study experimental work on winter wheat under the ARC/INRA collaboration programme.

M. B. Page, K. W. T. Goulding, J. B. Butler and M. Zahari bin Abu Bakar, were awarded their Ph.D. degrees, M. B. Page leaving to take up employment as a computer programmer in industry and M. Zahari bin Abu Bakar to return to Malaysia. J. G. Buwalda, from New Zealand, G. V. E. Pitta, from Brazil, Gamin M. Wang, from Brazil, and Karen S. Eide, arrived as research students, and R. Harrison, attached to Birmingham University, P. J. Reynolds to London University and G. Scott to Reading University all arived as CASE students. A. B. McBratney continued his studies on spatial variability. Our sandwich course student was J. Overton. A. R. Bromfield, with I. R. Hancock, returned from Kenya, to spend a period writing up results.

Professor Splittstoesser returned to America and Professor Webster to Canada after stays of 7 and 3 months, respectively. We welcomed Dr K. R. Tate from New Zealand in May, Dr N. Miyauchi from Japan in September, and Mr S. Shanmin from China in November, who are all here for 1 year. M. M. Fisseha returned to Aberdeen after a visit of 3 months. A. R. B. M. Atan returned to Malaysia and Dr C. C. Cerri returned to Brazil. Blanche Benzian continued to work on nitrogen content in grain.

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