Report for 1977 - Part 1

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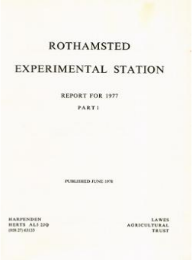

Soils and Plant Nutrition Department

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Introduction

This is the first Annual Report of the Soils and Plant Nutrition Department, which was formed on 1 March from the former Chemistry and Pedology Departments. Earlier reports on many lines of work dealt with here will be found under the headings of these departments in past *Rothamsted Reports*. There has for long been much common interest in topics pursued within the two Departments, for example in work on organic matter relationships in soil, the occurrence and value of trace elements, potassium release from clays, and soil structure. The new Department aims at a broad and integrated coverage of questions concerning soil composition and behaviour and the relationships of these with plant growth, leading to a progressively clearer understanding of the soil factors which determine crop yield.

The use of nitrogen by crops is of crucial importance to crop production now, since it involves problems of the economics of farming, the control of soil conditions to attain maximum yield, and possible pollution of surface water and aquifers. Much of the work reported here therefore deals with nitrogen. The use of nitrification inhibitors forms a potentially important development, since their action in field soils is now fairly well understood, but their useful application in practical agriculture still needs much investigation. More attention is given to denitrification in this report, and the precise measurement of N loss from this cause is still very difficult. There was some indication that the dry summer and wet autumn of 1976 led to unusually large drainage losses of nitrate, and our quantitative understanding of leaching processes in the field needs further improvement.

The soil organic matter studies are vital to work on both nitrogen nutrition and soil structure. From both points of view we are very interested in the effects of cultivation treatments on organic matter, and preliminary results this year indicate that the increase in breakdown rate following cultivation was smaller than expected. The model of carbon turnover in the soil described last year has been improved further.

The relationship of clay mineralogy to soil structure is now under investigation. The results are by no means clear-cut, and the implications of the presence of mixed-layer clays of varying composition requires further investigation. Work with new techniques will allow a progressively finer definition of the pore distribution in clay soils, in continuation of the work of the collaborative Soil Structure Group. A paper on the effects of management and manuring on the physical properties of soils at Rothamsted and Woburn will be found in Part 2 of the *Rothamsted Report*. The general conclusion confirms the major importance of the soil organic matter content, but the degree of its importance differs between soil types.

The use by plants of existing soil phosphate is of considerably greater importance now than a few years ago, due to price increases and the decrease of basic slag supplies. The problem is to determine how far the large existing reserves of previously applied phosphorus can be used without the loss of crop yield, and work reported here helps to determine the value of such residues precisely, and to determine how far they can be run down. This work will be extended with the recent arrival of staff to work on phosphate uptake by mycorrhizas.

Trace elements are now of interest in regard to pedological processes, to soil and crop deficiencies, and to excessive and toxic amounts in organic residues applied to soils. Their chemistry is exceedingly complicated in the soil, and this year we report work aimed at distinguishing the importance of complex-formation with organic compounds and inorganic ions in solution. Further information is now available about trace element distribution between different soils, and within single profiles, and our X-ray fluorescence equipment has been used for these and a variety of other trace element analyses.

As in previous years, a number of projects emphasise our links with overseas research. They cover denitrification in Sri Lanka soils, reclamation of acid sulphate soils in Thailand, ATP concentrations in Australian soils and mineralogical studies on soils from Bangladesh, Sudan and Nigeria.

Phosphorus residues in soils

Barley yields related to soil phosphorus during 1969–77 at Saxmundham. Changes in bicarbonate-soluble P have been measured at Saxmundham between 1965 and 1977 on the Rotation II experiment, which is sited on Beccles series soil. During this period potatoes, sugar beet and barley have been grown with and without dressings of superphosphate. The experiment aims to test effects of phosphate applied at differing times on $NaHCO_3$-soluble P in soil, and to relate this to crop responses. Here we consider the relationship with barley yields only. Methods of increasing soil P values between 1965 and 1968 have been given earlier (*Rothamsted Report for 1969*, Part 2, 91). By 1968 each of the soils in treatments 1 to 8 had a different amount of bicarbonate-soluble P ranging from 3 to 70 mg P kg^{-1}, giving soils in ADAS P Indices 0 to 4. Each treatment occupied one plot, approximately 40 × 5·5 m and in 1969 each plot was divided into four sub-plots and each sub-plot into five microplots, each approximately 3·56 × 5·5 m. The sub-plots were grouped into Series A and B, each of which contained the same P treatments. Each year root crops were grown on one Series and barley on the other, to give a root-barley-root-barley rotation. Tests of fresh P, as superphosphate, were made from 1969 to 1972 (Series A) and 1970 to 1973 (Series B) when dressings of 27, 55 and 82 kg P ha^{-1} were tested on the root crops on three of the microplots in each sub-plot, while the remaining two microplots received no fresh P. The barley following the root crops measured any residual effect of these P dressings.

In 1973 (1974 for Series B) the experiment was modified to compare three annual dressings of P, 27 kg ha^{-1}, to all crops and a triennial dressing of 82 kg ha^{-1} to the roots, in a rotation of roots, barley, barley. On both Series the second barley was followed by a third, in 1976 and 1977 respectively, to which no fresh P was given but where two rates of N were tested.

Each year the soils were ploughed in autumn to about 25 cm and the soil of each microplot was sampled in spring in alternate years before any fresh dressings of P were applied.

Table I summarises the treatments between 1899 and 1964 (for details see *Rothamsted Report for 1969*, Part 2, 91) the amount of P applied during 1965–67, the $NaHCO_3$-soluble P for whole plots in 1968 and for microplots receiving no fresh P in subsequent alternate years; the last values are the averages of soils in Series A and B. Where no P or only FYM was applied between 1899 and 1968 bicarbonate-soluble P changed little between 1968 and 1976, hence most of the P removed in the crops came from initially non-soluble

TABLE 1

Bicarbonate-soluble P in surface soils (0–25 *cm*) *following manuring and changes due to cropping in soils receiving no fresh P after 1967*, *Rotation II*, *Saxmundham 1968–76*

Treatment	Manuring* 1899–1964	Amount of P applied 1965–67 (kg ha^{-1})	Bicarbonate-soluble P, mg kg^{-1}				
			1968	1969–70	1971–72	1973–74	1975–76
1	None	0	3	5	4	3	4
2	FYM	0	7	8	7	6	7
3	FYM + P**	0	21	19	17	13	13
4	FYM + P	230	39	34	32	25	22
5	FYM + P	475	54	46	41	33	29
6	FYM + P	245	44	38	35	29	25
7	FYM + P	495	67	57	48	38	31
8	FYM + 2P***	0	29	28	26	21	19

* For details see *Rothamsted Report for 1969*, Part 2, 91

** 82 kg P ha^{-1} every 4 years

*** Until 1952

sources and barley yields averaged 3·27 t ha^{-1}. Increases in $NaHCO_3$-soluble P were given by either old (treatments 3 and 8) or recently applied P (treatments 4 to 7), and where this had happened, the value decreased during the test-cropping period of 1968–76.

From Table 2 it can be seen that yields and responses to new P related well to the $NaHCO_3$-soluble P in the four groups into which the soils can be divided, suggesting that the value of this soluble P to crops is the same whether it is derived from old or fresh residues.

TABLE 2

Yield of barley and response to extra P, Rotation II, Saxmundham 1970–77

Barley grain, t ha^{-1}, at 85% dry matter

Treatments	$NaHCO_3$-soluble P in 1975–76 (mg kg^{-1})	Yield 1970–77 Mean	Response to extra P Mean
5 and 7	30	4·99	−0·02
4 and 6	24	4·89	+0·09
3 and 8	16	4·61	+0·13
1 and 2	6	3·27	+0·94

It is not easy to test whether barley yields have declined as soluble P diminished because seasonal factors have a large effect on yield. Crops on plots with the highest value for soluble P (treatments 5 and 7) showed no sign of phosphorus deficiency, nor would one be expected, because these soils were in ADAS Index 3 even at the end of test cropping. Similarly with treatments 1 and 2, where the soluble P value did not change, and 4 and 6, where it did not decrease below the top of Index 2, there is no clear indication of a secular decrease in yield due to lack of P, but with treatments 3 and 8, where the Index decreased from 2 to 1, the mean yield was 0·38 t ha^{-1} less than on treatments 5 and 7, and the difference appeared to be increasing.

The value of large old residues of P for current crops is being measured on a range of soils; these results indicate that continued cropping without P fertilisers can reduce the soluble P level in such soils fairly rapidly, and that this level is an efficient indicator of the P supply to the crop. (Johnston, Poulton and Mattingly)

Evaluation of 'old' and 'new' residues in Saxmundham soils by isotopic dilution. Soil samples taken in spring, 1973 and 1974, from the Rotation II experiment were analysed for total P (P_t) and isotopically-exchangeable P (P_e). Yield, P uptake and labile P (L-values) were measured in a pot experiment with ryegrass grown in a controlled environment (16 h day; 20°C day/15°C night). These measurements were used to evaluate P residues from superphosphate and farmyard manure, applied at different times before sampling. Soils were bulked to give 16 treatments, eight having received no fresh P after 1968 and eight having been given 55 kg P ha^{-1} in alternate years between 1969 and 1972. The mean increase in P_t (by analysis) from the superphosphate applied at each rate was closely equivalent to the amounts of P applied, assuming the weight of soil (3920 t ha^{-1}) in the surface 25 cm used previously (*Rothamsted Report for 1969*, Part 2, 91–112).

L-values (mg P kg^{-1} soil) agreed well with P_e measured before cropping ($L = 1{\cdot}04\ P_e - 2{\cdot}6$) and P_e accounted for 95% of the variance in the L-values. The amounts of P removed (mg P kg^{-1} soil) in 3 cuts of grass (P_{crop}) were linearly related ($P_{crop} = 0{\cdot}30\ L - 5{\cdot}1$) to the L-values which also accounted for 95% of the variance in uptake. Negligible amounts of non-labile P (i.e. soil P that does not exchange with ^{32}P) were taken up by ryegrass in this experiment.

TABLE 3

P uptake by ryegrass, grown in a controlled environment, on soils from Saxmundham and isotopically-exchangeable P (L-values) in the soils

	P uptake ($mg\ P\ kg^{-1}$ soil)		L-value** ($mg\ P\ kg^{-1}$ soil)	
Treatment*	No P since 1967 or earlier	110 kg P ha^{-1} applied 1969–72	No P since 1967 or earlier	110 kg P ha^{-1} applied 1969–72
1	4·5	7·6	28	37
2	7·4	10·7	44	52
3	17·9	18·7	71	84
4	26·8	38·2	111	133
5	33·1	37·7	127	136
6	28·7	31·1	116	123
7	31·7	40·3	129	145
8	17·1	23·3	94	115
Standard error	±1·47		±3·3	

* for manuring, see Table 1

** weighted mean value from three cuts of grass

Yields of grass (not given), P uptakes and L-values all distinguished clearly (Table 3) between soils given no P fertilisers since 1964, or earlier (treatments 1, 2, 3 and 8), and soils given superphosphate or FYM from 1965–67 (treatments 4, 5, 6 and 7). More P was removed by ryegrass from soils given superphosphate (110 kg P ha^{-1}) between 1969–72 than from soils given no more P and L-values of these soils were larger, on average, by 13 ± 1·2 mg P kg^{-1} soil.

TABLE 4

Effects of P residues on increases in $NaHCO_3$-soluble P and isotopically-exchangeable P, as a percentage of increase in total P (ΔP_t) in soils from Rotation II, Saxmundham

	Year evaluated			
	1968		1973–74	
	$\Delta NaHCO_3-P/\Delta P_t$ (%)	$\Delta P_e/\Delta P_t$ (%)	$\Delta NaHCO_3-P/\Delta P_t$ (%)	$\Delta P_e/\Delta P_t$ (%)
P applied before 1964 and none since	11	37	10	43
P applied from 1965–67 and none since	25	60	15	45
P applied in alternate years, 1969–72	—	—	21	40

Table 4 compares the increase in $NaHCO_3$-soluble P (see p. 273) and in isotopically-exchangeable P (ΔP_e), as percentages of the increases in total P (ΔP_t) in the soils, with similar measurements made in 1968 (*Rothamsted Report for 1969*, Part 2, 91–112). Values for $\Delta NaHCO_3$-soluble P, as a percentage of ΔP_t, range from 10–25% and are smallest for soils to which no fertilisers had been applied since 1964 or earlier. Changes in both $\Delta NaHCO_3$-soluble $P/\Delta P_t$ and $\Delta P_e/\Delta P_t$ in these soils were negligible (Table 4) between 1968 and 1973–74 which suggests that both $NaHCO_3$-soluble P and exchangeable P were removed in the same proportions as total P by cropping in the field. Values of both ratios declined most between 1968 and 1973–74 on plots to which large amounts of superphosphate or FYM (230–495 kg P ha^{-1}) were applied between 1965–67. During this period the value of $\Delta P_e/\Delta P_t$ declined (Table 4) from 60% to 45%. By 1973–74, the value of $\Delta NaHCO_3$-soluble $P/\Delta P_t$ was about 15%, which is larger than on soils unmanured since 1964 but smaller than on soils given P between 1969–72.

These results show that pot experiments quantitatively evaluate residues from small dressings of phosphate fertilisers applied in the field. The increase in isotopically-exchangeable P (P_e or L-values) in chalky-boulder clay soils at Saxmundham, expressed as a percentage of the increase in total P in the soils, are similar (40–45%) to values obtained previously from long-continued applications of phosphate fertilisers to Clay-with-flints soils at Rothamsted (*Rothamsted Report for 1960*, 246–265). The percentage of the residue P in these soils which is soluble in 0·5M-$NaHCO_3$ changes more rapidly with time than $\Delta P_e/\Delta P_t$, and $\Delta NaHCO_3$-soluble $P/\Delta P_t$ approaches a value of about 10%. Relationships between desorbable P and $NaHCO_3$-soluble P in Rothamsted soils have been discussed previously (*Rothamsted Report for 1975*, Part 1, 89–90). (Mattingly, Halm, Chater and Brookes)

Investigations on potassium

Calorimetric analysis of potassium-calcium exchange. Heats of reaction for the exchange of Ca for K on Saxmundham soil (Beccles series) and Halton soil (Harwell series) were obtained by injecting small amounts of KCl into a suspension of Ca-saturated soil in 0·05 M-$CaCl_2$ in the LKB microcalorimeter. Preliminary tests involved mixing the soil as a < 250 μm powder with the $CaCl_2$ solution in the calorimeter reaction cell. Very poor mixing was achieved, giving variable heats of reaction. Much more reproducible results were obtained when the soil or clay was transferred to the calorimeter as a smooth paste of about 35% solid with water or 0·05 M-$CaCl_2$.

The heat of the exchange reaction was summed, giving a plot of the integral heat of exchange, ΔH_x, against percentage saturation with potassium (x). From this, a differential curve of $d(\Delta H_x)/dx$ against x was obtained; this showed regions of constant $d(\Delta H_x)/dx$. From the extent of these regions the approximately quantitative composition of a mixture of minerals having cation-exchange properties may be estimated, if the mineral species present are known. Extrapolation of the ΔH_x:x curve to $x = 1$ gives the total heat of exchange, $\Delta H_{x=1}$, of the reaction Ca→K, assuming that exchange equilibrium is attained at each step. This value and the standard enthalpy of exchange from exchange isotherm experiments were in good agreement for Saxmundham soil but not for Halton soil (Talibudeen and Weir, *Journal of Soil Science* (1972), **23**, 456–474). This suggests a lack of equilibrium in the clinoptilolite component (11%) of the latter, which requires 16 h for $>95\%$ equilibrium (Deist and Talibudeen, *Journal of Soil Science* (1967), **18**, 138–148) compared with 0·5 h per step allowed for equilibration in the calorimetry measurements. This lack of equilibrium in Halton soil also explains why $d(\Delta H_x)/dx$ increases with x, compared with the normal pattern of decrease with x observed with Saxmundham soil which results in an asymptotic value of ΔH_x at $x \rightarrow 1$.

Subsequent isotopic exchange experiments have shown that the mean fractional K saturation of 10 contrasting soils, saturated with Ca^{2+} for calorimetry (by several washes with 0·5 M then 0·05 M-$CaCl_2$), is 0·002, suggesting that the full integral heat cannot be measured in such experiments for soils containing micaceous clays, except perhaps at low temperatures (<5°C). Further experiments are in progress on contrasting soils to elucidate these points. (Goulding and Talibudeen)

Investigations on nitrogen

Nitrification inhibitors

For grass. Experiments in 1977 tested effects on ammonium and nitrate level in the soil and on yield and % N content of grass when N was given as injected aqueous NH_3, aqueous urea or aqueous urea plus ammonium nitrate (UAN), with or without either sodium trithiocarbonate (STC) or nitrapyrin ('N-Serve') as nitrification inhibitors. The effects of different spacings of injection knives were also compared.

Nitrification was slow during the winter 1976–77, presumably because of low soil temperatures. Ammonia applied alone in November did not nitrify completely until March and mid-May at Rothamsted and Woburn respectively, though nitrification was faster at Woburn in both previous years; when applied in March, it was detectable at both sites till mid-June.

NH_3 applied in November with either inhibitor was detectable until mid-May and mid-June at the two sites respectively. When it was injected in March with STC, NH_4 was detectable until mid-June, whereas where nitrapyrin was used, there was still an appreciable amount of NH_4 left at the last sampling, at the end of June, at both sites.

The inhibitors were effective in delaying nitrification, and should therefore lessen losses of NO_3 by leaching or denitrification, but their average effect on yield when injected with NH_3 in autumn was small. Table 5 gives mean results from experiments at Rothamsted and Woburn testing autumn and spring-injected aqueous NH_3, with and without inhibitors, against 'Nitro-Chalk'. The inhibitors had little effect on yield when applied in autumn, but in spring they slightly increased yields at Rothamsted and decreased them at Woburn. Autumn-applied NH_3 gave more grass than spring-applied at Rothamsted. Leaching effects cannot explain the effects of inhibitors with spring-applied NH_3, which may be due to the different value of NH_4 and NO_3 to the plants.

TABLE 5

Effect of N and nitrification inhibitors on dry matter yields of grass and nitrogen uptake after three cuts

	Nil	Fertiliser N applied (375 kg ha^{-1}) as					
		NH_3 (Nov.)**	NH_3 alone (Mar.)	NH_3 +STC* (Mar.)	NH_3 +'N-Serve'* (Mar.)	'Nitro-Chalk'	SED***
Rothamsted							
Yield (t ha^{-1})	6·0	11·6	11·1	11·5	11·8	12·4	0·51
N harvested (kg ha^{-1})	90	288	278	291	294	306	21·3
Woburn							
Yield	1·0	8·6	6·9	5·4	5·8	11·0	0·64
N harvested	13	192	142	114	126	221	13·1

* 10 kg CS_2, 2 kg nitrapyrin ha^{-1} respectively
** mean of all November applications, with and without inhibitor
*** not applicable to comparisons with NH_3 (Nov.)

UAN was also compared with NH_3 at both sites in spring. Both materials gave very similar yields at Rothamsted, but UAN gave 1·4 t ha^{-1} more dry matter than NH_3 at Woburn. STC with UAN appreciably increased total yield at Rothamsted (by 1·3 t ha^{-1}), but, as with NH_3, it slightly decreased it at Woburn.

The injection of the same amount per ha of NH_3 in fewer, more widely spaced slits makes application easier, but produces very large local concentrations of NH_3, leaves much of the grass a long way from the slits and causes alternate strips of lush and poorer growth. This year 30 cm and 60 cm spacings between slits were compared, in November and in March, using applications of 375 kg N ha^{-1}. Nitrification was slower with the wider spacing, except for November applications at Woburn. Total season's yields were little affected by spacing at Rothamsted, but 60 cm spacing at both application times gave 1·4 t ha^{-1} less dry matter at Woburn.

In a separate experiment at Rothamsted, continued since 1975 on the same site, different knife spacings were also tested, with three rates of N, given as either aqueous

TABLE 6

Yields of dry grass (t ha^{-1}) in 1977 from nitrogen fertilisers applied in 1977 and in 1976

	Nitrogen applied as				
	'Nitro-Chalk'	Aqueous urea			
		30 cm*		60 cm*	
		−STC	+STC	−STC	+STC
N given in 1977 (kg ha^{-1})**					
250	9·5	8·3	8·4	9·6	8·6
375	11·1	11·1	10·6	11·8	11·7
500	12·2	12·4	11·7	11·7	11·3
	S.E.D. ± 0·60				
Residues of N given in 1976 (kg ha^{-1})					
250	4·1	4·3	4·2	4·6	5·2
375	4·6	5·6	5·9	7·0	6·8
500	5·1	6·9	7·5	7·3	8·4
	S.E.D. ± 0·60				

* Distance between the bands

** Yield without N was 3·0 t ha^{-1}

urea injected in February or 'Nitro-Chalk' broadcast in six equal amounts from March to September. The two materials gave almost identical results. On average, 60 cm spacing between injection slits was slightly better than 30 cm because it increased persistency, but the addition of STC to the urea had no consistent effect on yield, though it slightly increased the residual value to crops in 1977 of N given in 1976. The residual value of all kinds of N given in 1976 is noteworthy.

Nitrification inhibitors are undoubtedly effective in delaying nitrification of autumn-applied NH_3 and urea. However, N injected in autumn under grass at Rothamsted is usually efficiently used even without inhibitors, though after the mild, wet winter of 1974–75, grass yields at Rothamsted were considerably improved where inhibitors had been injected with N the previous autumn. This benefit is more likely to occur in areas with heavier winter rainfall than at Rothamsted, and collaborative work with ADAS is now testing this possibility. The unexpected and irregular effects of using inhibitor in spring are difficult to explain at present, but merit more attention.

For winter wheat. Field experiments at Rothamsted and Woburn tested aqueous NH_3 and aqueous urea injected respectively in spring (1976) and in both autumn (1976) and spring (1977), with and without inhibitors, and compared them with broadcast 'Nitro-Chalk'. Autumn-applied N alone was equivalent to 50–60% of the same amount applied in spring. The rate of nitrification of applied N was measured (Ashworth *et al.*, *Journal of the Science of Food and Agriculture* (1977), **28,** 673–683), and, as before, both inhibitors delayed it substantially, especially nitrapyrin, but most N had nitrified by February. Both inhibitors increased the yield with autumn-applied N, by 0·34 t ha^{-1} grain on average, so that yields at Rothamsted closely approached those with spring-applied N, whereas at Woburn autumn-applied N was much inferior to spring-applied N, even with inhibitors. The different forms of N gave on average very similar yields, and the inhibitors on average slightly increased grain yield (by 0·13 t ha^{-1}), and % N in the grain when applied in spring.

Several subsidiary measurements were made on these experiments, including nitrate and total N in the wheat plants, flag leaf area, ear weight and % N. The effects of the inhibitors were small, although % N was slightly less in April and May, but slightly more in June with inhibitors, as would be expected from delayed nitrification.

A pot experiment compared the effects on spring wheat of calcium nitrate, ammonium sulphate, and the latter with CS_2 alone or with CS_2 + nitrapyrin. The last treatment damaged seedlings. CS_2 or combined inhibitors maintained low NO_3 concentrations in soils, though CS_2 alone was not completely effective on Woburn soil. The inhibitor treatments reduced plant nitrate concentrations, though the smallest value at 3 weeks was 400 ppm NO_3–N, even though soil concentrations were well below 1 ppm. On average, all treatments with applied N gave closely similar grain yields, though inhibitors, or fertiliser applied as nitrate, slightly increased % N in grain. Greatly enlarged flag leaves, and smaller, more numerous ears appeared on plants given $(NH_4)_2SO_4$ plus inhibitor. Plants grew normally on $(NH_4)_2SO_4$ alone or on $Ca(NO_3)_2$ plus inhibitor.

Inhibitor formulation. The stability of mixtures of nitrapyrin and CS_2 in aqueous emulsion was determined; most of both compounds had disappeared after 30 days, so this mixture is not suitable for commercial use. The stability of STC in aqueous NH_3 has given some cause for concern, but it was found that adding more (total 5 g litre^{-1}) NaOH gave an almost stable solution. The commercial formulations of nitrapyrin contain an organic solvent and an emulsifier, and phytotoxicity at dose rates supplying more than 15 ppm nitrapyrin in pot tests were traced to both these components. (Ashworth, Widdowson, Penny, Bird, Hewitt and Gibbs)

Soil N and take-all. There are reports that ammonium fertilisers decrease take-all, and the amount of NH_4 and the $NH_4 : NO_3$ ratio in the rhizosphere may be important (Hornby and Brown, *Plant and Soil* (1977), **48,** 455–471). This was investigated on extra plots added to the Woburn winter wheat experiment, which were injected in April 1977 with aqueous solutions of $(NH_4)_2SO_4$, NH_4NO_3 or $Ca(NO_3)_2$, applied alone or with a combination of nitrapyrin and CS_2.

Soil and plants were taken (avoiding injection slits) from these plots, and from those given N either as aqueous urea or NH_3 injected in October 1976, or as 'Nitro-Chalk' broadcast in April 1977. Samples of soil from between rows of plants ('bulk') and soil crumbs adhering strongly to roots ('rhizosphere') were extracted and analysed for NH_4 and NO_3; the roots were also examined for take-all. Bulk soil samples had less NO_3 where inhibitors had been used, but rhizosphere soil was unaffected; there was no consistent difference between the pH of rhizosphere and bulk soil.

In August take-all was prevalent (40% of plants infected) but not damaging on this second successive wheat crop. Disease increased most rapidly where NH_3 or urea had been applied in autumn, but less so where inhibitors were also given. Rate of increase of take-all tended to be smaller on plots given no N, and least of all on plots given N in spring, especially as aqueous solutions. Inhibitors had little or no effect on this small incidence of take-all. (Ashworth and Widdowson, with Hornby, Plant Pathology Department, and Brown, Soil Microbiology Department)

The effect of spring-applied nitrogen on the growth and nutrient uptake of winter wheat. Winter wheat (var. Atou), grown on Little Hoos (pH in water 8·0, 1·5% $CaCO_3$) and given 0, 100 or 200 kg N ha^{-1} as 'Nitro-Chalk' in April, was sampled every 3–4 days between April and harvest (*Rothamsted Report for 1976*, Part 1, 87). Dry matter yield, % N, P, K, Ca and Mg were measured.

Patterns of growth and nutrient uptake were similar to those observed in 1976. One hundred kg N ha^{-1} increased the rate of growth between tillering and anthesis but 200 kg N ha^{-1} had no further effect. Grain yield behaved similarly.

Percent N in the ears and foliage increased with applied N at all stages of development. During tillering and stem extension, the rate of N uptake was increased by and related to the amount of applied N, but during heading, rates of N uptake were similar in all treatments. The first level of applied nitrogen increased N accumulation in the ears, but it was not increased further by the second level.

The concentrations of P, K, Ca and Mg in the foliage also increased with the amount of applied N, particularly during the early stages of growth. The greatest effect was on % Ca, presumably to maintain cation- a nion balance during uptake. Applied N had little effect on the concentration of these nutrients in the ears. The rates of P, K, Ca and Mg uptake were increased by the small dressing of N during tillering and stem extension. The heavy dressing of N increased further the uptakes of K and Ca, except in the ears. In all treatments, % P, K, Ca and Mg were largest in the plant at Feekes' stages 11·3, 10·5, 11·1 and 11·2 respectively, and % N was maximum at maturity.

Generally, applied N did not greatly affect the pattern of uptake or prolong the retention of nutrients in the plant. The small dressing of N increased dry-matter yield and uptake of nutrients considerably, but the heavy dressing rarely had much further effect. (Page, Lister and Talibudeen)

Slow-release nitrogen fertilisers for potatoes, and their residues. Slow-release N fertilisers could benefit potato crops by continuing to supply N when the tubers are bulking and by lessening the delay in tuber initiation and development that can occur with large N dressings. Their residues should be less subject to leaching than those from conventional fertilisers and therefore better available to following crops.

In 1976, Pentland Crown potatoes were given 200 or 300 kg N ha^{-1} as aqueous ammonia, alone or with nitrification inhibitors (nitrapyrin at 1·1 kg ha^{-1} or ammonium trithiocarbonate at 18 kg ha^{-1}), as isobutylidene di-urea (IBDU) in large (1·5–2·4 mm) or small (0·8–1·5 mm) granules, or as ammonium nitrate. The last was also applied as a split dressing. Ammonium nitrate at 150, 250, 350 and 400 kg N ha^{-1} was also tested.

The dry weights of haulms and tubers and the numbers of tubers were measured on six occasions. Two hundred and 300 kg N ha^{-1} gave closely similar results, and the averages are in Table 7. By 9 June, plants given IBDU or the split ammonium nitrate dressing had formed more tubers than those given other N treatments. The differences in tuber numbers had disappeared by 12 July, though the dry weight of tubers per plant was

TABLE 7

Effects of the N sources on growth and yield of potatoes, 1976, and yield of following winter wheat, 1977

	Means for 200 and 300 kg N ha^{-1}				
		Dry wt (g) per plant on 12 July		Yield (t ha^{-1})	
N source	No. of tubers 9 June	Tubers	Haulm	Tubers 1976	Grain 1977
Aq NH_3					
Alone	1·2	43	49	48·5	6·2
+nitrapyrin	2·4	49	55	47·4	6·6
+$(NH_4)_2CS_3$	3·2	38	50	48·3	6·2
IBDU					
Small	5·9	58	44	47·9	6·9
Large	4·1	57	45	47·4	6·8
NH_4NO_3					
Split	6·9	54	42	52·3	6·3
Single	3·1	58	51	49·5	6·2
SED	±1·40	±8·7	±4·5	±2·16	±0·22

still larger with IBDU or split ammonium nitrate than with aqueous ammonia. By harvest (13 October) tuber yields differed little from each other.

Winter wheat (var. Atou) was sown on these plots on 10 December, top-dressed with 'Nitro-Chalk' giving 70 kg N ha^{-1} on 9 April 1977 and harvested on 9 September. Yields were significantly larger on plots that had received IBDU than on the rest, but aqueous ammonia with nitrapyrin also gave slightly larger yields. (Addiscott, Ashworth, Penny and Widdowson)

Measuring denitrification in soils. The continuous gas flow-through system described earlier (*Rothamsted Report for 1976*, Part 1, 96–97) was used to study denitrification losses in sieved soil from Eden's Trial, Tea Research Institute, Talawakele, Sri Lanka. The data for 0–15 cm and 15–30 cm samples were respectively: pH 4·1, 4·0; organic carbon 4·5 and 3·9%; total N 0·26 and 0·25%; NO_3^-–N 9·5 and 49·0 mg kg^{-1}; NH_4^+–N 18·9 and 27·0 mg kg^{-1}.

Denitrification (i.e. N_2 and N_2O evolution) and CO_2 loss were measured by gas chromatography in soil incubated at 25°C and ¾ (water holding capacity). The effect of four levels of O_2, of N as KNO_3 and $(NH_4)_2SO_4$, and of added glucose, have been investigated.

The '15–30 cm' soil did not denitrify under any of these conditions, and much less CO_2 was produced than by the '0–15 cm' soils. This suggests that the activity of the soil micro-organisms is very low at the 15–30 cm depth. Evolution of N_2 and N_2O, which accounted for nearly all the gaseous N losses from surface soil, occurred only at the lowest oxygen tensions, 0% and 0·5% O_2, but not at 5% and 20% O_2. The rate of loss of gaseous N was constant, and added glucose simply extended the period of denitrification. Evolution of gaseous N_2 lagged behind that of N_2O, and production of CO_2 increased with total N_2 and N_2O evolution. When denitrification ceased, the rate of CO_2 production decreased immediately to a constant minimum value, presumably due to the fermentative reactions of mixed flora of soil bacteria.

With added $(NH_4)_2SO_4$–N, only the indigenous NO_3^-–N denitrified. Adding glucose to the soil had little effect on gaseous nitrogen losses from added KNO_3 or $(NH_4)_2SO_4$, but more CO_2 was produced. (Wickramasinghe and Talibudeen)

Assaying denitrification capability. Estimates of nitrogen efficiency are complicated by the difficulty of measuring denitrification losses. Current methods of determining denitrification in the field by ^{15}N mass spectrometry or gas chromatography require sophisticated equipment, and estimates by difference of the other nitrogen inputs and outputs are imprecise. An accurate, simple and inexpensive method to measure denitrification capacity is therefore desirable.

Respiratory nitrate reductase, the first enzyme in the sequence of enzymes responsible for the reduction of nitrate to nitrogen gas and/or nitrous oxide, lacks specificity for nitrate and can reduce a variety of cations and anions, including bromate, chlorate, perchlorate and the ferric ion. Reduction of such alternative substrates may offer a method to measure denitrification capacity, if not absolute rates, in the field.

Chlorate or iodate mixed with anaerobic soils in sealed jars were not reduced to any significant extent, probably because their reduction produces toxic compounds (e.g. chlorite). Bromate was reduced under both anaerobic and aerobic conditions, even in the presence of metabolic inhibitors. This suggests that bromate, a relatively strong oxidising agent, is reduced chemically. Tellurite reduction could not be measured due to difficulties in extracting and determining the ion when added to soil. Selenite (added as selenous acid) was reduced under anaerobic conditions, and reduction was greatly decreased by metabolic inhibitors, to an extent approximately equal to that of the same inhibitors acting on nitrate reduction. However, selenite was reduced under aerobic conditions, which implies that some alternative enzyme system may reduce selenite. Reduction of the native ferric ion in soils to ferrous ion occurs under anaerobic conditions and results support earlier work (reviewed by Thauer *et al.*, *Bacteriological Reviews* (1977), **41,** 100–180) suggesting that this reduction is mediated by respiratory nitrate reductase. Both nitrate and ferric ion reduction required anaerobiosis, a viable soil microflora and reduced carbon substrate in the soils tested. Reduction rates of ferric ion were correlated with those for nitrate when tested with different soils and temperature regimes, and nitrate competitively inhibited ferric ion reduction.

Future work will be directed towards screening further inorganic ions and ferric ion for reduction, and measuring reduction rates to determine denitrification potential and denitrification rates *in situ*. (Rodgers)

Nitrogen in cereal grain. The results from 20 years of experiments conducted by Rothamsted on its home farms and nearby commercial farms are being examined to see how the experimental treatments and certain environmental factors have affected the nitrogen concentrations of grain, how these are related to yields, and whether the commonly observed negative correlation between yield and % N always applies.

The computer listing of all the data for winter and spring wheat and for barley (*Rothamsted Report for 1976*, Part 1, 85–86) was completed a year ago, and has proved useful for exploratory manual and computer plotting. Computer scatter diagrams in which yields are plotted against % N in grain for all winter-wheat (about 2000) and spring-wheat values (about 400) had well-defined boundaries. Forty per cent of N concentrations in winter wheat and 75% in spring wheat were equal to or greater than the minimum values agreed for bread wheat under the 'Home-Grown Cereals Authority's revised voluntary UK milling and wheat classification scheme' for the 1976/77 season (10% protein on a 14% moisture basis). By adding lines of equal N uptake (or 'protein yield') to these diagrams, crops grown under widely differing conditions can be compared.

Results from winter-wheat experiments carried out by ADAS in central southern England (Batey and Reynish, *Journal of the Science of Food and Agriculture* (1976), **27,** 983–990) and at Boxworth Experimental Husbandry Farm, Cambridge (Bowerman and Clare, *Experimental Husbandry* (1976), **30,** 42–54) fall within the range of our own yield and % N data. (Benzian, with Lane, Statistics Department)

Drainage and leaching

Rainfall, evaporation, and nitrate in drainage water at Saxmundham. For the period 1 October 1976 until 30 September 1977 the rainfall at Saxmundham Experimental Station was 621 mm, which is 8 mm less than the long period average (1937–76). Rainfall between 1 April and 31 July was 116 mm, 50 mm less than the previous 10 year mean and only 9 mm more than during the dry summer of 1976. From 1 April to 30 September 1977 evaporation (E_0), measured by pan evaporimeters, was 448 mm and accumulative moisture deficit was 135 mm. Solar radiation at Saxmundham between the beginning of June and the end of August 1977 was about 30% less than the same period in 1976.

There was continuous drainage between 25 September 1976 and 15 April 1977, and between the latter date and 30 September 1977 there were 145 days without drainage. Losses of nitrate N in drainage from 1 October 1976 until 30 September 1977 were much more than for the previous year, 51 kg ha^{-1} was lost from the arable section and 22 kg ha^{-1} from land mainly under herbage crops. Most nitrate was lost during the period of heavy rain that lasted from September to December 1976, when concentrations of up to 40 mg NO_3–N litre^{-1} were measured in drainage from all sections of the field.

Nitrate N in borehole waters at Rothamsted and Woburn. Concentrations of nitrate N in borehole waters sampled at Rothamsted Farm between 1 October 1976 and 30 September 1977 varied from 5·0 to 8·3 mg litre^{-1} (mean 6·1 mg litre^{-1}). Corresponding values in mains supply water at Rothamsted were 5·8 to 9·3 mg litre^{-1} (7·8 mg litre^{-1}) and in borehole water at Woburn, 1·7 to 7·7 mg litre^{-1} (5·9 mg litre^{-1}).

Small increases (1–2 mg litre^{-1}) of nitrate N above values for the previous year were measured in the borehole waters at both sites after January 1977, probably resulting from the exceptionally dry summer of 1976. There was thus a delay of about 6 months after very heavy rainfall in the period September to December 1976. The increases were slight and at no time did levels exceed the WHO recommended limit of 11·3 mg litre^{-1} for nitrate N. (Williams)

Soil acidity

Acid sulphate soils. Previous recorded attempts to improve the condition of acid sulphate soils by liming have been unsuccessful because continued oxidation of residual pyrite prevented any improvement in yield from persisting after the first year (Hart *et al.*, *Agronomie Tropicale* (*Paris*) (1963), **18,** 800–802). However, some acid sulphate soils from the Bangkok Plain gave a large and sustained response to moderate liming, from which it would seem that these soils no longer contain any reserves of unoxidised pyrite. Analysis of three representative profiles confirmed this; in one of these no pyrite was detected down to 130 cm, although the pH, sulphate content, and the presence of jarosite showed that pyrite had once been present throughout the profile.

Within the top 50 cm of the profile of two marled soils from Chacheongsao Land Development Centre, the pH ranged from 5·58 to 6·40; the pyritic sulphur content first became measureable (0·19%) at 40–50 cm, and increased rapidly with depth to $>$1·0%, while the pH decreased equally rapidly to 3·6. The distribution of pyrite in the unmarled soil was much the same, but the pH decreased from 3·8 in the 0–10 cm horizon to around 3·3 throughout the rest of the profile. From the information at present available it seems that the marled soil received 6 t marl ha^{-1} some 6–7 years ago, and as the improvement in yield has persisted to the present the possibility that economically feasible liming would permanently improve these soils seems worthy of consideration. (Bloomfield and Pruden)

Labile aluminium in aluminosilicate minerals

Kinetics of release. The rates of release of Al into M ammonium nitrate (pH 3) from mineral presaturated with Al ions at pH 3 was measured in experiments reported last year (*Rothamsted Report for 1976*, Part 1, 97–98). Analysis of this data indicates the following processes. For all minerals a diffusion-controlled release of Al from the matrix core of the mineral grains occurred, the diffusion coefficients being in the order muscovite mica$>$biotite$>$illite$>$montmorillonite$>$kaolinite (0·25–0·5 μm and 1·5–2·5 μm). There was also release from peripheral layers, which obeyed first order kinetics for kaolinite and montmorillonite, but was diffusion-controlled in illite and biotite, and did not occur at all in muscovite. An instantaneous release of Al from the immediate surface occurred with 0·25–0·5 μm kaolinite and montmorillonite.

According to models proposed in previous work, the ionic composition of the instantaneously released Al varied with the mineral from 3 to 100% Al^{3+}, the remainder being in the hydrolysed form, and the apparent hydrolysis constants were different for each mineral and from those of Al ions in solution.

Acid-base titrations of adsorbed ions. Acidified suspensions of Al saturated kaolinite, montmorillonite, mica, illite and biotite in 10^{-3} M-$NaNO_3$ were potentiometrically titrated with 0·1 M-NaOH and 0·1 M-HCl in a CO_2-free atmosphere. The resulting curves were compared with those given by $Al(NO_3)_3$ solutions of composition similar to the supernatant solutions in the mineral suspensions.

Base titration curves of adsorbed Al ions showed inflexions and plateaux of buffering which were less pronounced and at lower pH values than with $Al(NO_3)_3$ solutions. The more complex buffering of adsorbed Al points to its resistance to reaction with added OH^- because of the strong binding on mineral surfaces of hydroxy-polymeric Al ions, whose composition cannot be inferred solely from these titration curves.

The OH^- used by adsorbed Al ions between the first and last inflexions was equal to, or slightly greater than, the CEC of the mineral except for mica, where it was more than twice its CEC, possibly due to dissolution of Al in the acid pre-treatment.

Acid titration curves of adsorbed Al ions and of those in solution showed hysteresis in relation to base titration curves. The use of two titration speeds (20 m and 3 h per pH unit) affected only slightly the titration curves of the minerals suggesting that the observed effects were not caused by lack of equilibrium with added base or acid. (Cabrera and Talibudeen)

Soil organic matter

ATP content of the soil biomass. A new method was developed for extracting and measuring adenosine 5′-triphosphate (ATP) in soil. Soil was dispersed ultrasonically for one minute in a solution containing trichloracetic acid (0·5 M), orthophosphate (0·25 M) and paraquat (0·1 M). The ATP content of the filtered extract was then determined in a liquid scintillation counter by the firefly luciferin/luciferase system. The extractant was designed to minimise sorption of ATP on the soil colloids after its release from disrupted cells.

There was a close linear relationship ($r = 0{\cdot}98$) between ATP content and biomass (measured by the fumigation technique) in a heterogeneous group of South Australian soils. Biomass can be calculated from the ATP content by the relationship

$$\text{Biomass C in soil, } \mu g\ g^{-1} = 120\ (\text{ATP in soil, } \mu g\ g^{-1}).$$

(Jenkinson, with Dr. J. M. Oades, The Waite Agricultural Research Institute, Adelaide. This work was done during the tenure of a Hannaford Fellowship by Jenkinson at the Waite Institute)

The effect of cultivation on the decomposition of soil organic matter. The mechanical disturbance of soil during ploughing and seedbed preparation may increase the rate of decomposition of soil organic matter, and this could make more nitrogen available to crops than in a minimum tillage system. However, preliminary results suggest that this effect may be small. Soil nitrate concentrations were measured after a cultivation treatment (ploughing followed by rotavation) was given to plots on two areas of bare soil; one area had previously grown grass and the other wheat. Leaching losses were prevented by covering with shelters. One week after cultivation the soil that had previously grown wheat contained only 3 kg ha^{-1} more NO_3–N in the plough layer than the corresponding uncultivated soil. On the areas that had previously grown grass the difference in nitrate content between cultivated and uncultivated soil was barely detectable.

The rate of mineralisation of soil organic matter in cultivated and uncultivated soil was studied by measuring carbon dioxide evolution from the soil surface, using a modification of the method of Monteith, Szeicz and Yabuki (*Journal of Applied Ecology* (1964), **1,** 321–337). Cultivations were done in November 1976 and repeated in June 1977. On both occasions cultivation doubled the amount of carbon dioxide evolved during the following 24 h, but during the next 24 h carbon dioxide evolution was similar from both cultivated and uncultivated soil and after this more carbon dioxide was collected from the uncultivated soil. It is not yet clear whether these are real effects or, at least partly, artefacts caused by the method of measurement. Soil biomass was measured at the end of the experiment and was found to be unaffected by cultivation. These results suggest that the extra nitrogen mineralised as a result of cultivation is small. (Powlson and Jenkinson)

In contrast to the field measurements, disturbing the soil in a large soil tank (by digging to a depth of 15 cm) increased soil respiration for several weeks. Air was passed over the surface of the soil in these tanks and the carbon dioxide collected in absorption tubes containing soda lime (Currie, *Ministry of Agriculture, Fisheries and Food, Technical Bulletin* (1975) No. 29, pp. 461–468). During the first week after disturbance carbon dioxide evolution was increased by 60% and was still 10% higher in the 6th week.

Comparison of the method used for measuring carbon dioxide evolution in the field with the soil tank method showed that the amounts of carbon dioxide measured in the field were low. The absorption of carbon dioxide by soda lime, as in the method of Monteith *et al.* (1964), can be increased by increasing the area of soda lime exposed, but it seems questionable whether any method of measuring carbon dioxide evolution from the soil surface which creates a carbon dioxide 'sink' above the soil can give reliable absolute values. (Powlson, with Currie, Physics Department)

Soil organic matter decay models. Work has continued on the model for the decay of organic matter in soils, developed to fit measurements on the Rothamsted Classical experiments (Jenkinson and Rayner, *Soil Science* (1977), **123,** 298–305). A more realistic treatment has been given to the biomass component by allowing a proportion of decaying biomass to become new biomass immediately. In the original model organic matter was assumed to enter the soil in annual pulses: the effect of continuous steady additions of plant material has now been calculated for comparison. For continuous input the biomass has a steady value amounting to 23·3% of the annual input; with pulsed input the biomass component varied during the year from 21·6% to 24·3%. (Rayner)

Soil structure

Physical behaviour of clay soils. The collaborative work on six soils undertaken for the Rothamsted Soil Structure Working Group, has continued. Shrinkage on drying of fresh soils samples of Hanslope series has been measured and as with the other subsoils, the transition from normal to residual shrinkage is distinct and occurs at a moisture content of about 0·2 g g^{-1} oven-dry soil. Moist soil has been critical-point dried and pore size distributions by mercury porosimetry will be completed shortly.

We are comparing the mercury porosimetry results with moisture retention determinations between 100 mbar and 15 bar tensions. Comparisons so far between values for Evesham, Denchworth and Ragdale soils show that mercury porosimetry cannot detect pores larger than 30 μm or smaller than about 3 nm, but it has not yet been possible to resolve whether the pores of variable geometry that shrink during drying are larger or smaller than 0·3 μm diameter. Results on the other three soils may clarify this.

Mercury porosimetry has been adversely criticised as a technique for pore size measurement, hence it is important to have independent methods for determining pore size distribution. We have tested and obtained first results from organic liquid retention techniques, using a high boiling range (200–260°C) petroleum fraction in a conventional sintered glass tension plate apparatus and a pressure membrane apparatus containing a cellulose ester membrane. With these two techniques, we can measure pore size distribution between about 200 and 0·1 μm, but extension to smaller pore sizes requires a vapour pressure technique and a more volatile liquid, and this has not yet been set up. (Newman and Perrins)

Soil water-structure relationships and clay mineralogy. The swell-shrink properties and pore size distributions of five contrasting soils containing 50–60% clay were measured by Greene-Kelly and the clay mineralogy has now been determined on these soils. The Evesham series soil on Oxford Clay (30:70), the Challow series on Gault Clay (80:20) and the Gezira vertisol (80:20) all contain dominant amounts of mixed-layer smectite: illite (the proportions being indicated in the brackets); the Halstow series on Culm shale contains much discrete coarse mica and some mixed layer smectite:illite (60:40), whereas the Micklefield series soil on Permian Marl is dominated by an unusual mixed layer mineral that may be partially ordered. The effect of mineralogy on soil physical properties is complex, but certain relationships between them can be seen in some of the soils studied. For example, the Gezira vertisol and the Challow series soil are very similar both in mineralogy and in physical behaviour; although the Gezira soil shows a larger shrinkage after remoulding, a cycle of drying and wetting eliminated this difference. The physical behaviour of the Evesham and Micklefield soils was quite similar in spite of very evident differences in their mineralogy, but neither swelled as much as the Challow and Gezira soils, although the Micklefield tended to have a more open structure after a cycle of wetting and drying. The Halstow series soil showed more residual shrinkage but less normal shrinkage than the other soils and the pore size distribution is little changed by a cycle of drying and wetting; this is probably a reflection of its micaceous mineralogy, but it may also be important that this soil contains more free Fe and Al oxides than the others.

Clay mineralogy has been determined on four of the soils used in the Rothamsted Soil Structure Working Group project. In the Evesham series soil from the margin of the Oxford Clay vale, a mixed layer smectite-illite (Random, 60:40) dominates the clay fraction and is probably responsible for this soil having a lower bulk density than the Hanslope series soil on Boulder Clay. The Denchworth series soil is also dominated by a smectite:illite but the relative proportions are 40:60 approximately. The Flint and Salop series soils on reddish tills derived from Triassic rocks have clay fractions composed of mica and smectite-illite with minor amounts of other clay minerals, but the mixed-layer mineral does not seem to be a simple random interstratification of expanding and mica layers. (Branson and Newman)

Mineralogy

X-ray diffractometry of clays

Extra intensity. Alterations to collimating condition which lead to large increases in intensity were reported in last year's Report, and some possible applications have now been explored further. Clay minerals can be determined in many soils without size fractionation by X-ray examination of soil ground for 30 s in a Tema Swing Mill. If reliable estimates of minerals such as feldspar and quartz in the coarser fractions are required, further grinding in, for example, acetone in a mechanical agate mortar, produces suitable material. Samples are examined as randomly oriented powders, and these methods of specimen preparation appear to prevent preferred orientation of platy clay minerals. They allow the normal diagnostic treatments for identification, but do not require treatments used in separating the clay fraction and preparing oriented films, such as boiling with hydrogen peroxide, which may selectively destroy some of the finer materials. Information is also obtained from the same diffraction patterns about the minerals in the sand and silt-sized fractions, which if separated would require separate examination. The method has been tested on a range of soils from Britain and overseas, and has been found to be applicable, for clay mineral analysis, to samples containing more than 10–20% clay-sized material.

The extra intensity also allows better quantitative determination of small proportions of minor components in unfractionated soils. For example, 0·2–2% lepidocrocite has been determined in whole soils. The limiting factor in the quantitative determination of lepidocrocite, goethite and similar minor components, is not lack of sufficient intensity but interference by reflections from minerals present in major amounts such as feldspars and quartz. The extra intensity has also allowed some characterisation of very poorly ordered materials such as ochre from field drains by study of their X-ray scattering. (Brown)

Continuous 'background' scattering at small angles on diffractometer patterns of clays. It is frequently assumed that the continuous 'background' scattering on diffractometer patterns of clays, which is largest at small angles, is caused by scattering of X-rays by air, and Johnson (*Clay Minerals* (1977), **12,** 93–95) has described a device for the artificial suppression of this effect from the diffractometer record. It has now been shown that the often large background intensity in this region is not caused by air but arises from X-rays scattered by the specimen even in a properly adjusted diffractometer. For a selection of dominantly kaolinitic clays the intensity of the continuous background in the 2–10° (2θ) region correlates well with other features of their diffraction patterns that indicate structural disorder in the kaolin minerals. (Brown)

Deposits found in field drains. Characterisation of the minerals in the deposits formed in field drains installed in 1972 at the Arthur Rickwood Experimental Husbandry Farm, near Chatteris, Cambridgeshire, has continued. The orange-brown ochre layer consists essentially of a bacterially-produced hydrous iron oxide which resembles ferrihydrite. The white Al-rich layer, which seems to be a chemical precipitate, shows some resemblance to allophane. Orange-brown ochreous material is frequently found in field drains, but the white material has not been reported before. The latter, when present, always occurs below the ochre layer and so must have formed first; it differs from allophane in containing more Al_2O_3 and less SiO_2. The formation of substantial amounts (a 1 cm layer in a 7 cm diameter pipe) in less than 3 years shows that dissolution and neo-formation of soil minerals is an active process in these soils, and it can take place rapidly even in cool temperate regions. (Ormerod and Brown)

Mineralogy of Nigerian soils. The variation in kaolin crystallinity in the clay fraction of some Nigerian soils (*Rothamsted Report for 1976*, Part 1, 226) has been correlated positively with aspect ratio, and negatively with surface area and CEC, measured at pH 3·1. The crystallinity index of the kaolin becomes greater with increasing age of the soil and decreasing rainfall.

Correlation of the crystallinity index of the kaolins with the soil classification, using Soil Taxonomy (USDA, 1975) suggests that more attention should be paid to mineralogical data in classifying tropical soils. This is particularly necessary for the many tropical soils of which the clay fractions are dominated by 1:1 layer silicates and oxides. The crystallinity index of the kaolins may be an aid to subdivision in a way that is useful for predicting soil behaviour. (Hughes and Brown)

Application of infrared spectrometry to clay mineralogy. We have made a study of dioctahedral smectites to find out which infrared spectral information could be used to infer the approximate composition and distribution of charge between the octahedral and tetrahedral sheets. Fine clay fractions ($<0·2$ μm) of the Wyoming, Otay, Chambers and non-ideal montmorillonite types of smectite were separated and analysed chemically.

Spectra were recorded from pressed KBr discs and where necessary from oriented films supported on AgCl and polyethylene.

Assignments for OH-vibration in the 750–950 cm^{-1} region are reasonably certainly established and depend on octahedral compositions; the spectra indicated quite clearly the substitution of Fe and Mg for Al in the octahedral sheet and a similar correlation between composition and absorbence frequency was also found for soil clays. It seems therefore that this spectral region is reasonably diagnostic of octahedral composition. Vibrations of the Si-O network are complex and not all observed bands in the spectral regions 400–600 and 950–1200 cm^{-1} have been assigned with certainty. (Branson and Newman)

Other projects. The clay mineralogy of a lake-bed sample from the South Chad Irrigation Pilot Project was determined. A smectite-like interstratified mineral comprised almost half of the clay fraction, kaolinite accounted for about one-third and mica for most of the remainder. Soil samples from the 18–36 in horizon of five profiles from Bangladeshi tea plantations were examined. Kaolin minerals, vermiculite-like minerals, smectite-like interstratified minerals, mica, gibbsite, quartz, goethite and feldspar were found in each profile. The mineralogy of muds from the Blue Nile and the Suez Canal was determined. (Brown, Ormerod and Rahman)

Soil forming processes

Chiltern brickearths. In addition to the thin Late Devensian loess, which is an important topsoil constituent on Rothamsted Farm and elsewhere on the English Chalk outcrop, a few soils on the Chilterns are developed partly in a somewhat different silty deposit. This occurs sporadically on the dipslope plateau in irregular, funnel-shaped depressions penetrating the usual Clay-with-flints subsoil often to the Chalk beneath. One example, on Little Knott (Rothamsted Farm), is approximately 100 m across and $>5{\cdot}5$ m deep in the centre. Others at Caddington and Gaddesden Row contain Acheulian (Palaeolithic) implements, which indicate an age considerably greater than the Late Devensian loess.

We have compared the mineralogy, particle size distribution and trace element content of these deposits with the Clay-with-flints, the Devensian loess and some older loesses from Kent and East Anglia. In particle size distribution the brickearths resemble loess, but commonly contain more clay and/or sand. The mineralogical composition of these fractions shows that the additional material could be derived from the Clay-with-flints, but some features of the clay fractions indicate they have also been fairly strongly weathered. In particular, the expanding clay minerals contain components of chlorite-vermiculite intergrade material, which have formed by precipitation of hydrated aluminium oxide polymers in smectite interlayers; this aluminium was probably derived from the edges of clay particles by acid weathering.

Interpretation of the silt mineral assemblages is complicated because they are mixtures of several components, all but one of which contain the same suite of minerals but in slightly different proportions. Principal co-ordinate analysis suggests that the silt fractions contain loess which resembles either Wolstonian loess at Northfleet (Kent) or the yet older Anglian loess at Barham (Suffolk), and also variable amounts of material derived from Clay-with-flints. The amounts of various trace elements (As, Br, Cu, Ni, Pb, Rb, Sr, Y, Zn and Zr) determined in whole soil samples by X-ray fluorescence techniques, and also subjected to principal co-ordinate analysis, suggested similar origins for the deep brickearths. The Clay-with-flints and loesses of different ages are distinguishable by their trace element assemblages, and the brickearths can generally be interpreted as mixtures of Clay-with-flints and older loesses.

We therefore conclude that the brickearths were washed into the depressions (probably old swallow holes) by streams flowing across surrounding land surfaces at various times in the Middle Pleistocene. They were derived from strongly weathered soils developed in loesses, which were deposited originally in the Wolstonian and Anglian cold periods. These loesses rested on and were partly mixed with Clay-with-flints, probably in much the same way as Devensian loess overlies Clay-with-flints in the present soils of the Chiltern plateau. (Catt, Rayner, Weir and Wilkins)

Geochemistry

The geochemistry of reclaimed sediments from The Wash. Comparisons of soil profiles formed by reclamation of saltings at Friskney, Lincs. showed differentiation of chemical composition, both with age from reclamation and with depth down the profile. For example, Zn and Sr showed a clear decrease with increasing age since reclamation, there was most Pb and Br in very recently reclaimed sites, and Zr concentration showed a definite increase with increasing age from reclamation. These differences are most apparent in the topsoils (0–15 cm) and disappear below about 45 cm. Although the soils are too young to be greatly differentiated down the profile, Zn, Cu, Pb and Br are clearly concentrated at the tops of the profiles. This may be due to the accumulation of these elements by overlying vegetation. (Wilkins)

The frequency distribution of minor elements in soils. Data from a geochemical survey of Pembrokeshire soils (*Rothamsted Report for 1971*, Part 1, 82) have been examined to see if the frequency distributions of the elements are normal or whether the data would be represented better after transformation. Logarithmic, reciprocal and square root transformations were tested; some variates (Rb, pH) were normally distributed, some were better represented by a square root transformation (Zr, Fe) and others were log-normally distributed (Y, Sr, Pb, Br, As, Cu, Ni, Mn and loss on ignition). However, samples of soils developed on any one parent material had many more normally distributed populations of minor elements than samples from the whole of Pembrokeshire. This work suggests that the common practice of doing a log transformation of all geochemical survey data is not always advantageous, but may be useful for Mn, which has a very broad and skew distribution in soils, and for samples with distributions with very long 'tails', such as populations which include a number of polluted samples. (Palin and Wilkins)

Trace elements

Complexing of copper in soils by inorganic anions. The aim of this work is to assess the comparative importance of organic materials and of inorganic anions in complexing copper in the soil solution. A Cu^{2+}-sensitive electrode was used to measure the extent of complex formation between cupric ions and humified organic matter, derived from Rothamsted soil or from incubation of plant material. Complexing by organic matter predominated at copper and complexant concentrations similar to those of saturation extracts of normal soils, but complexing by the bicarbonate ion, to form soluble copper carbonate complexes, became significant as the copper concentration increased towards that of sewage-sludge amended soils. The extent of copper complexing by bicarbonate was unaffected by the presence of calcium ions, though the latter compete with copper for organic complexing agents. Nitrate and sulphate had no significant complexing effect at the concentrations likely to be present in the soil solution, and phosphate precipitated rather than complexed copper; however phosphate enhanced copper complexing by organic material, presumably because of the formation of mixed copper-phosphate-organic matter complexes.

In a continuation of this work we are measuring the relative effects of bicarbonate and of soluble humified organic material on the adsorption and desorption of copper by and from materials in the soil solid phase. (Bloomfield and Sanders)

Incubation of trace metal oxides and plant residues. We have studied the influence of oxides of trace elements on the rate of mineralisation of plant material decomposing aerobically in the presence of kaolin, quartz sand or Rothamsted subsoil (Broadbalk Wilderness, stubbed section, 18–27 in). During the first few days' incubation iron (III) oxide caused an increase in the rate of mineralisation but had little effect on the subsequent rate. Manganese (IV) oxide did not affect the mineralisation rate and the other metal oxides we tested inhibited mineralisation; over a 3-month period the order of effectiveness of inhibition is

$$\mathrm{Co} < \mathrm{Zn} < \mathrm{Ni} < \mathrm{Pb} < \mathrm{Cu}$$

which is nearly the same as the order of the relative degree of complexing of these metals by the soluble products of the aerobic decomposition of plant matter.

We are now studying the effect of incubating iron (III), manganese (IV) and copper (II) oxides with aerobically decomposing ground pea pod shells, in the presence of kaolin, upon the extractability of these elements by water, 0·1 M-sodium pyrophosphate, and 0·1 M-sodium hydroxide. (Bloomfield and Sanders)

The effect of V.A. mycorrhiza on the uptake of heavy metals. Vesicular-arbuscular (V.A.) mycorrhiza can improve the phosphorus nutrition of their host plant, and enhance Zn concentrations in plant tissues. This experiment tested the effect of mycorrhizal infection on the growth and heavy metal uptake of onion, and the effect of heavy metals on the extent of the fungal infection. Onion was chosen as a test crop because it becomes strongly mycorrhizal and is also resistant to heavy metal toxicity.

The partially sterilised (1 M rad) soil received a basal nutrient mixture and additions (in mg kg^{-1}) of: Zn, 10 and 75; Cu, 5 and 25; Cd, 0·1 and 1; Ni, 5 and 25; P, 5 and 25. Onions were grown in the soil in pots, half of each treatment being inoculated with spores and mycelium of *Glomus mosseae*. After ten weeks in a glasshouse, plants were harvested and analysed. The extent of infection in the roots was estimated by an adaptation of the method of Marsh (*Journal of Applied Ecology* (1971), **8,** 265–267).

Mycorrhizal infection enhanced phosphate uptake by the plants in all treatments. Similarly, zinc uptake was higher in all mycorrhizal treatments, except where cadmium was given. Copper uptake was slightly increased by mycorrhizal infection in the controls, the low Zn and both copper treatments. Mycorrhiza formation had little effect on the uptake of cadmium or nickel at the levels used in this study. All heavy metal treatments reduced the extent of the infection, and with high Zn and Ni it was prevented. The levels of heavy metal which prevented infection occurring also caused physiological damage to the plant. (Gildon and Tinker)

Effects of blue-green algae on growth of potato plants

Algae appear to affect plant growth, though their biological fixation of atmospheric nitrogen is quite low (Witty *et al.*, *Rothamsted Report for 1976*, Part 2, 111–118). Potato plants were grown in the glasshouse in buckets, such that they formed tubers in a peat-filled compartment. The soil surface was either inoculated with blue-green algae (*Nostoc* sp.) or covered with Al foil to prevent algal growth. The plants were given two rates of N (167 or 667 mg kg^{-1} soil), in one or two doses, and two rates of K (167 and 830 mg kg^{-1} soil).

With the larger N rate given all at the start the algae increased plant height very considerably, though when the N application was split, the increase was small. At the final harvest, there were no significant effects of algal inoculation at the small N rate, but at the larger rate, top, root and tuber weights were increased, significantly so where the N dressing was not split. The increases in growth at the large N rate suggest that the algae influenced growth by releasing growth substances rather than fixing N. (Rodgers and Addiscott)

Leaf protein extraction

The feed mechanism of the extraction unit is now a set of robust angled paddles that do much of the work of leaf disintegration before pressing begins. This modification needed a stronger drive which disconnects automatically when there is an incipient overload, and the new system now works smoothly. The speed differential between the feeding and pressing sections of the unit, which we think advantageous, is given by an epicyclic gear. The unit has been demonstrated at a Nutrition Society meeting. We are now making a slightly larger model.

Measurements of the amount of phenolic material in the leaves of various species, and in leaves from plants of the same species but differing in age, agree with the idea that phenolics interfere seriously with protein extraction. For example, hazel leaves, from which it is difficult to extract any protein at all, have a 'phenolics to total protein' ratio five times as great as that of an easily extracted leaf, such as winter wheat, at a comparable age. Similarly, as an easily extracted leaf ages, the ratio can increase by a factor of three, while the percentage of protein extracted diminishes by the same factor.

A growing interest in coppiced trees as sources of paper pulp and energy suggests that by-product tree leaves could be a source of leaf protein. Of the small number of trees examined, only elder leaves extract well. Alkali and sulfite must be added to get any protein out of other tree leaves, presumably because of the presence of phenolics. We have attempted to pre-treat these leaves to elute the phenolics before pulping liberates protein, but so far we have been unsuccessful. (Butler and Pirie)

Methods, apparatus and techniques

A comparison of methods of watering pots and the effects on the yield and nutrient uptakes of ryegrass. Descriptions of pot experiments often give detailed accounts of soil preparation and plant nutrients supplied but little about methods of watering. Much of our experimentation depends upon proper control of such experimental detail. A comparison of the effects of watering techniques and pot sizes on the yield and nutrient uptake of ryegrass *Lolium perenne* (S23), was made using two pot sizes. Ryegrass was grown in the pots in a constant environment room. Water was supplied by adding it to the soil surface once or twice a day to give 80% of water holding capacity (WHC), by keeping the saucers under the pots half filled or via a wick inserted through the pot base, from an external container. Three harvests were taken at 28-day intervals. The grass from each pot was dried, weighed and analysed for N, P, K.

Pots watered via the saucers produced the largest yields in the larger pots and also greatest phosphorus uptake in both pot sizes, while those watered by the wick method produced lowest yields and nutrient uptakes. However, N and K uptakes were greatest in pots watered to constant weight once or twice a day.

These results differ from those reported previously (*Rothamsted Report for 1966*, 62) where it was found that under glasshouse conditions, watering to 80 or 100% WHC produced larger ryegrass yields than watering in saucers. The wick method was undependable, but very good reproducibility was obtained in all three other methods, though the different nutrient recoveries and growth emphasise the importance of exact control in the operation. (Brookes and Gildon)

Determination of pyritic sulphur in coal shale. We have taken part in a collaborative study of methods of determining pyritic sulphur in mine waste. Although treatment with H_2O_2 gives complete oxidation of pyrite in soils, this treatment is not sufficiently drastic when dealing with coal shale. The effect is probably mechanical, as the recovery of total sulphur after oxidation with H_2O_2 increased with decreasing particle size of the shale. Roasting shale with $NaHCO_3$ at 500°C gave complete oxidation of pyritic and organic S; oxidisable S was determined as the difference between the total- and sulphate-S, the latter being determined on a 2N-HCl extract of the original shale. (Bloomfield and Pruden)

Determination of ammonium, asparagine and glutamine amide nitrogen in plant material. Deficiencies of most nutrients are associated with the accumulation of free amino compounds, largely asparagine and glutamine. Estimation of these two amides may therefore be helpful in assessing soil nutritional status.

The method of Henderlong and Schmidt (*Plant Physiology* (1966), **41,** 1102–1105) has now been adapted for the estimation of ammonium and the amide nitrogen of asparagine and glutamine in 80% (v/v) ethanol extracts of grass, but using steam distillation and titration for the estimation of ammonium.

The amended method gave excellent recoveries with standard mixtures, and the results of analysis of six different samples of grass were in good agreement with those obtained using ion-exchange chromatography, as described by Nowakowski, Bolton and Lazarus (*Journal of the Science of Food and Agriculture* (1975), **26,** 1483–1492). The errors of measurement were 2·2% of the mean for asparagine and 4·9% of the mean for glutamine, for results in the range 1·5–9 mg g^{-1} of dry grass. (Nowakowski and Lazarus, with Lane, Statistics Department)

X-ray fluorescence spectrometry. Investigations of the fusion process in sample preparation for major element analysis by the technique of Norrish and Hutton (*Geochimica et Cosmochimica Acta* (1969), **33,** 431–453) has shown that different brands of fusion mixture (quoted as the same composition) have very different loss on ignition values, which affect results of analyses. Corrections can be made when computing the results. (Devonshire and Wilkins)

Gamma spectrometry. A NaI(Tl) detector, coupled to a Canberra multichannel analyser, has been calibrated over the energy range 0·28 to 1·12 MeV for a geometry suitable for the analysis of mixtures of gamma-emitting radionuclides in soil. A computer program has been written which processes the data from the analyser, plotting the gamma spectra to enable the analysis to be made. (Smith)

Routine analyses for radioactivity. Approximately 7000 samples, with β energies ranging from 156 keV to 3·5 MeV, were assayed for radioactivity using the Beckman liquid scintillation spectrometer; 67% of these samples originated in other departments. (Smith)

Analytical section. The total number of analyses done was 80 600 (4·3% more than last year). These include crop and soil solution preparation, pH measurement, Kjeldahl digestion, and anion and cation analysis. 16% of the total was done for other departments. (Cosimini)

SOILS AND PLANT NUTRITION DEPARTMENT

Staff and visiting workers

The Chemistry and Pedology Departments were amalgamated and became the Soils and Plant Nutrition Department on 1 March, when P. B. Tinker arrived to take up his appointment as Head of the new Department. T. Z. Nowakowski retired in June, after 19 years on the staff. At the invitation of the University of Western Australia, G. G. Briggs left to spend a year in the University's Soils and Plant Nutrition Department, to undertake research on pesticides in soil. A. R. Bromfield continued his work in Kenya for the Ministry of Overseas Development (ODM) on sulphur cycles in East African agriculture. J. Bolton returned from Indonesia, having completed his secondment to ODM to work in Sumatra with the Indonesia/United Kingdom Transmigration Project. In August he attended a meeting of Commissions IV and V of the International Society of Soil Science in Kuala Lumpur, Malaysia on 'Classification and management of tropical soils', financed by ODM. In September he visited the Waite Agricultural Research Institute and CSIRO Division of Soils in Adelaide, Australia. D. S. Jenkinson returned after nine months at the Waite Agricultural Research Institute, supported by the Hannaford Fund, and three months with CSIRO Division of Soils, supported by the Division. Jenkinson spent one week visiting research centres in Perth; this was financed by the University of Western Australia, the W.A. Department of Agriculture and CSIRO Division of Land Resource Management. He also visited research centres in New Zealand at the invitation of the New Zealand Society of Soil Science.

During February/March, O. Talibudeen visited the Soil and Water Management Centre at Haryana Agricultural University, Hissar, India at the invitation of UNESCO/UNDP, for discussion of research programmes at the Centre and to help organise a seminar on ion exchange and mobility in soils related to crop growth. He gave invited papers in April at the 3rd Colloquium on Microcalorimetry at Chelsea College and at an FAO Experts' Consultation on 'The better exploitation of plant nutrients' in Rome. N. W. Pirie was invited by the Society for International Development to visit Paris in March to judge the semi-finalists in the Mitchell Prize Essay Contest organised by the Society. Later he visited Dublin for discussions about leaf protein, and Hungary to attend a meeting of an *ad hoc* committee of the International Council of Scientific Unions and to visit the Institute of Biochemistry in Budapest. Pirie was also invited to visit Empresa Geral de Fomento in Lisbon. In December, at the invitation of the British Council, he went to Brazil for a conference on the use of agricultural wastes as food and feed. C. Bloomfield visited Thailand and West Malaysia in April on behalf of ODM, and gave a paper at a meeting on toxic metals in sewage sludge, organised by the Department of the Environment. The Agricultural Research Council sponsored F. V. Widdowson's visit to France in May for a meeting of the Anglo-French Cereal-Agronomy Liaison Group at the Institut National de la Recherche Agronomique. The Council also financed A. H. Weir's visit to Oslo, Norway in July where he attended the third European Clay Conference. P. B. Tinker spent 3 weeks in Nigeria towards the end of the year as one of a team invited by the Technical Advisory Committee of the Consultative Group on International Agricultural Research to review the research programme of the International Institute of Tropical Agriculture, Ibadan, Nigeria.

M. C. Igbokwe was awarded a Ph.D degree by London University.

A. J. Gibbs (fertiliser experiments) arrived in March, and D. P. Stribley and R. C. Snellgrove were appointed in the autumn to work on mycorrhiza and other biological problems in plant nutrition.

The following were visiting workers in the department: Mrs. A. Chiriac (Romania), Mr. A. Gildon, Dr. M. C. Igbokwe (Nigeria), Mr. Z. Karim (Bangladesh), Miss H. H. Masha-Ala (Iraq), Professor M. Miyaguchi (Japan), Mr. A. Rahman (Bangladesh), Mr.

K. N. Wickramasinghe (Sri Lanka) and Dr. I. S. Webb. Jo Anne Chilcott, R. E. Leverton, Anne Lister and P. T. Richardson were sandwich course students.

Publications

BOOK

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GENERAL PAPERS

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