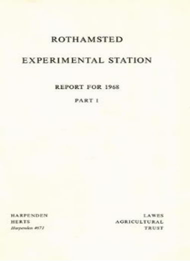
Report for 1968 - Part 1

Full Table of Content



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CHEMISTRY DEPARTMENT

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The largest single practical problem in the nutrition of modern farm crops is to use efficiently the very large amounts of nitrogen fertiliser needed. British farmers spend about £60 million each year on nitrogen, and its use has had an important part in the large increases in yields achieved during the last 25 years. However, much of the total is used inefficiently. Too few farmers adjust their dressings to allow for soil type, previous cropping and manuring, or for the weather; consequently some crops get too much, and this can diminish yields of cereals and root crops, whereas others on poor soils get too little. In some years much nitrogen is leached because it is applied with too little regard to weather. The average given for grass is still much too small to produce economically satisfactory yields. With these considerations as background, it is not surprising that more than half of our Report describes work with nitrogen fertilisers. However, the intensified cropping made possible by using nitrogen, brings other problems we report on. Supplies of magnesium in many light soils not given organic manures have become too small to support large yields for long. The problems we describe with 'exhausted' soil at Woburn are typical of those now increasing on much light land in England. We record what we believe to be the first examples of sulphur deficiency in field experiments in England. While so much sulphur-containing fuels are burnt, our air and rain will supply enough for crops over most of Britain, but the deficiency may become more than a scientific curiosity in areas remote from industry.

A new range of problems of a different kind are caused by herbicides. In any one year most arable land receives either selective herbicides applied to growing crops, 'pre-emergent' ones applied to seedbeds, or ones that destroy all green plants. Although these materials are mostly beneficial, their behaviour and fate in soils needs detailed study. Our experiments show that some herbicides may interfere with crops unexpectedly and that their action on weeds and crops may depend on previous manuring and management. In addition to the risk of loss of yield, such effects may complicate the interpretation of experiments where all the crop receives a herbicide. We are trying to find how the chemical structure of herbicides, microbial activity and soil properties govern the persistence and breakdown, of some of the materials now used.

Nitrogen fertilisers

Anhydrous (82% N) and aqueous ammonia (25% N) on permanent pasture at Rothamsted. Both sorts of ammonia, injected either in November or in March, were compared with dressings of 'Nitro-Chalk' applied either all at once in March, or divided equally between March, May and July. Each N fertiliser was applied to give 2·0, 3·0, 4·0 or 5·0 cwt N/acre, to permanent pasture that had been grazed for many years; it was cut in May, July and October. On this field there was little advantage from applying

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more than 2 cwt N/acre which increased dry yields roughly by 1 ton/acre.

Table 1 shows that all the nitrogen fertilisers increased yields at the first and second cuts, but decreased them at the third. Ammonia injected in November gave larger yields at the first cut than either spring-injected ammonia or broadcast dressings of 'Nitro-Chalk'; aqueous ammonia increased yields a little more than anhydrous ammonia. The 'Nitro-Chalk' scorched the grass and checked it; presumably this explains the smaller yields. At the second cut, yields with all the fertilisers were similar; at the final cut, 'Nitro-Chalk' decreased yields more than the other fertilisers. The wet weather and lack of sunshine probably explain the yield losses. (Widdowson, Penny and Flint)

TABLE 1

Mean yields from four amounts of each fertiliser

cwt/acre of dry grass

		Ammonia in autumn		Ammonia in spring		'Nitro-Chalk'		
	No nitrogen	Anhydrous	Aqueous	Anhydrous	Aqueous	Single	Divided	Standard error
1st cut	21·2	34·9	36·1	32·9	34·4	32·5	33·7	±0·78
2nd cut	18·2	25·8	27·3	28·0	26·9	27·0	26·0	±0·60
3rd cut	23·5	21·6	23·0	22·4	22·9	21·5	19·5	±0·92
Total	62·8	82·3	86·4	83·4	84·2	80·9	79·2	±1·44

Anhydrous ammonia and other liquid fertilisers on grass

Spacing. An experiment on a long ley on Parklands tested the effects of different patterns of injected NH_3 on yield and N recovery. Ammonia supplying 200 or 400 lb N/acre was injected (on 25 March) 4 in. deep at 36 points/sq yd in three patterns

(1) at square spacings 6 in. × 6 in.
(2) 3 in. apart in rows 12 in. wide
(3) 2 in. apart in rows 18 in. wide.

The grass was cut in May, July and August; 2-ft squares were harvested from plots without fertiliser-N and those having the square spacing, and

TABLE 2

Effect of ammonia injected at different spacings

Spacing	Cut 1	Cut 2	Cut 3	Total (3 cuts)
	Total *extra* yield of dry grass per plot g/m²			
6 × 6 in.	124	114	51	289
12 × 3 in.	121	180	69	370
18 × 2 in.	71	121	70	262
	% of applied N recovered			
6 × 6 in.	24	16	6	46
12 × 3 in.	22	21	8	51
18 × 2 in.	13	16	10	39

https://doi.org/10.23637/ERADOC-1-123

2-ft strips, each 3 in. wide and parallel to the centre row, from plots with ammonia injected in rows.

Injecting ammonia in rows 12 in. apart gave most dry matter and the grass recovered most N (Table 2). Where NH_3 was applied in rows, the yield of the strip 0–3 in. from the centre line was taken as 100, and yields of the other strip or strips were expressed as percentages (Table 3). When

TABLE 3

Effect of distance from line of injecting NH_3 on grass

(averages of rates of application)

	Cut 1	Cut 2	Cut 3
	Increases in dry matter as % of 0–3-in. strips		
Fertiliser in rows 12 in. apart			
0–3 in.	100	100	100
3–6 in.	72	76	127
Fertiliser in rows 18 in. apart			
0–3 in.	100	100	100
3–6 in.	91	143	194
6–9 in.	40	58	63
	Fertiliser-N recovered, as % of 0–3 in. strip		
Fertiliser in rows 12 in. apart			
0–3 in.	100	100	100
3–6 in.	72	82	107
Fertiliser in rows 18 in. apart			
0–3 in.	100	100	100
3–6 in.	74	112	142
6–9 in.	32	54	72

ammonia was injected in rows 12 in. apart, the 3–6-in. strip yielded less than the 0–3-in. strip at the first and second cuts and more at the third. With 18-in. rows, the 3–6-in. strip yielded slightly less than the 0–3-in. strip at the first cut, about half as much again extra yield at the second and nearly twice as much at the third cut. The strip 6–9 in. from the injection line always yielded less than the central area. The recovery of fertiliser-N followed the same pattern, although grass sometimes produced proportionally more dry matter than nitrogen recovered. (Blakemore and Gasser)

Effective area fertilised. Known volumes of solutions of ammonium hydroxide, ammonium nitrate and nitric acid were injected on 6 May at 4 in. deep under established grass to give dressings equivalent to 200, 400 and 800 lb N/acre, as above. The grass was cut in concentric circles of 6 in., 12 in. and 18 in. diameter around the point of injection; harvested areas were in ratios 1 : 3 : 5. At the first cut (17 June) ammonium hydroxide produced less extra dry matter than the other two forms and at the second cut (14 August) much more. The yield from both cuts was slightly more with ammonium hydroxide and nitric acid than with ammonium nitrate, as was the amount of fertiliser-N recovered. The yields from the three annular rings at the first cut showed that the outer ring given ammonium hydroxide had less dry matter and N than the outer ring around

https://doi.org/10.23637/ERADOC-1-123

ammonium nitrate and nitric acid. The amounts of N recovered in the first cut showed that nitric acid moved most; the extra N recovered in 2 cuts from the fertiliser in the three rings was:

	Distance from injection point (in.)		
	0–3	3–6	6–9
	Fertiliser-N recovered g/ring		
NH_4OH	0·194	0·196	0·116
NH_4NO_3	0·184	0·166	0·082
HNO_3	0·139	0·202	0·159

These values are, of course, from unequal areas. Yields and uptakes for unit areas are expressed below by taking the 0–3-in. zone as standard and averaging amounts and forms of N; relative yields and recoveries per unit area were:

	Distance from point of injection (in.)		
	0–3	3–6	6–9
Relative increase in yield	100	60	31
Relative recovery of fertiliser-N	100	50	22

Fertiliser-N recovered per unit area was halved between 0–3 in. and 3–6 in. and halved again at 6–9 in. Dry matter decreased slightly less. (Gasser and Blakemore)

Anhydrous ammonia and 'Nitro-Chalk' for spring wheat. Table 4 shows the average yield of spring wheat in five experiments made since 1966, three at Rothamsted and two at Woburn. 'Nitro-Chalk' gave considerably larger yields than anhydrous ammonia at 0·5 cwt N/acre, but only slightly larger at 1·0 or 1·5 cwt N/acre. Thus, anhydrous ammonia seems less efficient than ammonium nitrate, and when used for spring wheat more N than usual should be given. (Widdowson, Penny and Flint)

TABLE 4

Average yields of spring wheat in five experiments (1966–68)

	N applied, cwt/acre			
	0·0	0·5	1·0	1·5
'Nitro-Chalk'	18·3	31·1	35·5	37·0
Anhydrous ammonia	18·9	25·7	34·1	36·7

Liquid fertilisers for barley. Four experiments made with spring barley not only compared yields from aqueous ammonia (25% N), and from a solution of urea (18% N) injected in bands 12 in. apart and 4 in. deep, with yields from equivalent broadcast dressings of ammonium nitrate (as 'Nitro-Chalk', 21% N), but also with those from a liquid NPK fertiliser (14–6–8)* and a granular NPK fertiliser (20–10–10)*; the liquid was combine-drilled or sprayed, the solid combine-drilled or broadcast.

Table 5 shows a sizeable increase from drilling PK fertiliser (with broadcast N); aqueous ammonia and the solution of urea both gave

* Here and elsewhere in this Report compound fertiliser analyses are given in this abbreviated form; thus 14-6-8 implies a compound fertiliser with 14% N, 6% P_2O_5, 8% K_2O.

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almost the same yield as broadcast ammonium nitrate. There was a small gain from drilling a 'starter' dose of N. Granular 20–10–10 gave smaller yields when broadcast than when drilled and, with 1·0 cwt N/acre, smaller yields than drilling P and K alone and broadcasting or injecting the N. Thus, some of the advantage of combine-drilling was lost because this amount of N checked early growth and so diminished yield. Liquid 14–6–8 (based on urea and diammonium phosphate) gave smaller yields than the granular 20–10–10, presumably because some of the urea soon hydrolysed to ammonia, which was wasted when the fertiliser was sprayed over the seedbed and severely checked early growth when it was combine-drilled; the double dressing killed many plants.

TABLE 5

Mean yields of spring barley from four experiments with N and NPK fertilisers

Yields of grain at 15% moisture content: cwt/acre

Without fertiliser 15·7

	Fertilisers applied to give	
Fertiliser tested	0·5 cwt N/acre	1·0 cwt N/acre
Broadcast 'Nitro-Chalk'	24·2	27·2
Broadcast 'Nitro-Chalk' + 0–20–20 drilled	29·5	32·3
Injected aqueous ammonia + 0–20–20 drilled	29·0	33·1
Injected aqueous ammonia + 6–15–15 drilled	29·2	34·0
Injected solution of urea + 0–20–20 drilled	29·4	33·2
Broadcast granular 20–10–10	26·5	30·8
Drilled granular 20–10–10	29·0	31·4
Sprayed liquid 14–6–8	24·6	28·7
Drilled liquid 14–6–8	27·4	27·5

The experiments also tested the effect of combine-drilling a weak solution of formalin; this had no consistent effect on yields and will not be tested again, but the other treatments will. (Widdowson, Penny and Flint)

IBDU. Work with this slow-acting fertiliser, which began in 1967 (*Rothamsted Report for 1967*, pp. 39–40) was continued at Rothamsted and Woburn. At Rothamsted the residual effects of fertilisers applied in 1967 were measured by cutting the S22 ryegrass in May and again in June. Table 6 shows that yields of grass and N uptakes in 1968 were largest from the largest granules of IBDU, and were larger from all grades of IBDU than from ammonium nitrate. The total yields for the two years did not differ significantly between the IBDU fertilisers, all of which gave larger yields than ammonium nitrate; small and medium granules were significantly better. In contrast to yields, most N was taken up during the two years from ammonium nitrate (82% of that applied). Least was taken up from the large granules of IBDU (56% of that applied) and its better performance in the second year did not compensate for the slow release of N in 1967.

At Woburn fertilisers were applied in a new experiment; S22 ryegrass was sown in March and cut in June, August and October. Table 6 gives total yields. At the first cut ammonium nitrate produced most grass and

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TABLE 6

Ammonium nitrate and IBDU on grass

(Yields of dry matter and N uptakes are averages of 100, 200 and 300 lb N/acre applied)

	Rothamsted				Woburn 1968	
	Yields (cwt/acre)		N uptake (lb/acre)		Total yields cwt/acre	N up-take lb/acre
	1968	Total 1967 + 1968	1968	Total 1967 + 1968		
Ammonium nitrate	14·0	83·9	20·6	230	68·3	182
IBDU						
Powder	19·6	88·7	27·3	214	67·8	170
Small (0·5–0·8 mm) granules	22·5	92·3	32·6	216	69·6	169
Medium (0·8–1·5 mm) granules	27·6	92·9	40·9	204	66·9	158
Large (1·5–2·4 mm) granules	33·4	86·5	51·3	177	62·2	142
No nitrogen	11·1	35·7	16·0	65	14·7	27
Standard error	±1·0	±2·5	±1·7	±8	±1·3	±4·2

response to the IBDU fertilisers diminished as particle size increased. At the second cut differences between the fertilisers were small. The third cut reversed the differences at the first, and the largest granules of IBDU produced most and ammonium nitrate least grass. Nevertheless, total yields, as at Rothamsted in 1967, were more with the other fertilisers than with large IBDU granules, which supplied less nitrogen during the year. (Gasser, Penny and Flint)

Previous cropping, nitrogen fertiliser and barley yields. An experiment made at Rothamsted from 1965–1967 (*Rothamsted Report for 1967*, p. 43) was repeated on a more fertile field from 1966–68. Wheat, kale or Italian ryegrass were grown in 1966 with 0·0, 1·0 or 2·0 cwt N/acre. Barley was grown in both 1967 and 1968, with 0·0, 0·5 or 1·0 cwt N/acre. Each year the N tests with barley were made in all combinations with all the previous treatments. Table 7 shows that in 1967 barley yielded much less after grass than after wheat or kale. The difference was largest when barley was not given N (14·4 cwt/grain/acre) and smallest with 1·0 cwt N/acre. Yields

TABLE 7

Effects of crop sequence and nitrogen on barley

Yields of grain at 15% moisture content: cwt/acre

	N applied, cwt/acre			
	0	0·5	1·0	Standard error
Crop in 1966	1967 grain yields			
Wheat	36·6	40·3	38·9	±0·64 V*
Kale	37·0	43·5	41·1	±0·69 HI*
Italian ryegrass	22·6	36·8	38·4	
	1968 grain yields			
Wheat	29·0	25·2	25·1	±1·66 V*
Kale	33·6	26·7	23·7	±1·80 HI*
Italian ryegrass	36·4	26·3	22·2	

* V = For vertical comparisons.
HI = For horizontal and interaction comparisons.

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were larger after kale than after wheat, but sizeably so only when the barley was given N. Applying 2·0 cwt N/acre for the ryegrass increased barley yields by 4·0 cwt/acre, whereas N applied for wheat or kale left no worthwhile residue. Hence the adverse effect of grass on barley was less when the grass was given N. Similarly, applying 1·0 cwt N/acre instead of 0·5 cwt to barley increased yields only after ryegrass, and decreased yields after wheat and kale. Even 1·0 cwt N/acre may be too little for maximum yields after the ryegrass ley.

In 1968 the barley lodged completely on plots given N and partly on the unmanured plots. Table 7 shows that the largest yield was from unmanured barley where ryegrass was grown two years ago and least after wheat. Applying nitrogen for the barley consistently decreased yields.

The yields of unmanured barley were increased by residues from the N applied in 1966 to the other crops, and especially to the ryegrass, which increased yields by more than 5 cwt per acre. This combination of crop and fertiliser residues produced the largest mean yield in 1968 (39·5 cwt/acre), almost 10 cwt/acre more than after wheat, and 5 cwt more than after kale; these results show how important it is to adjust nitrogen manuring for previous cropping and manuring. For some unknown reason, the N mineralised from the grass roots was more beneficial to barley than fresh fertiliser N. (Widdowson, Penny and Flint)

Forms of fertiliser-N, water and spring wheat. Wheat grown in plots under a glass roof was given ammonium sulphate or ammonium nitrate (both treated with nitrification inhibitor 2-chloro-6-(trichloromethyl)-pyridine) or calcium nitrate. Some plots were watered so that the surface soil was always near 50% WHC, some were not watered during tillering, others during stem extension, and others during earing. When watered throughout the season, the wheat given calcium nitrate yielded most dry matter (and grain) and took up the most N, but when water was restricted, yields and N uptake were similar with all three fertilisers, probably because the soil was rich in available-N. Withholding water during stem extension or earing (when ears and florets develop) decreased the yields of grain, by making ears lighter, and increased the amount and proportion of fertiliser-N left in the straw. Watered throughout the season, the wheat contained about half as much NO_3^--N during its vegetative growth with ammonium sulphate as with calcium nitrate. Plants not watered during tillering or stem extension contained less NO_3^--N than watered plants.

Wheat grown in deep pots kept in a glasshouse was given ammonium sulphate (treated with the nitrification inhibitor) or calcium nitrate, applied to the surface and/or to the bottom layers of soil, and different pots were watered differently. When the soil was uniformly wetted to 50% WHC, calcium nitrate produced more wheat grain than ammonium sulphate, but less when water was restricted so that only the bottom or the top of the pot was at 50% WHC. With full watering, calcium nitrate provided more N to grain and straw than ammonium sulphate; with restricted watering, the whole plant took up similar amounts of N from each form of N but more entered the grain from ammonium sulphate. The wheat recovered more fertiliser-N from the bottom layer than from the surface soil.

https://doi.org/10.23637/ERADOC-1-123

In the field and the glasshouse, adequately watered wheat yielded most dry matter and grain (and contained most N) when given calcium nitrate, but yields with ammonium sulphate were as good, or better when water was limiting. (Spratt and Gasser)

Formalin and nitrogen

Barley at Saxmundham. In this experiment described in last year's Report (p. 57), formalin was applied in February, in all combinations with the previous application. All the other treatments were repeated on the same plots:

Yield of grain in cwt/acre

No formalin	Formalin applied 1967	Formalin applied 1968	Formalin applied 1967/8	
36·6	38·6	39·0	38·9	±0·87

Formalin increased yields by 2·0 cwt/acre (±1·19) where applied in 1967 only, by 2·4 cwt/acre where applied in 1968, but only by 2·3 cwt/acre where applied in both years. Lime had little effect, and the largest differences in yield reflected differences between varieties and effects of giving calcium nitrate in different amounts and at different times.

Table 8 shows that Deba Abed yielded more than Maris Badger, especially with 1·2 cwt N/acre, which caused the Maris Badger to lodge and yield less than with 0·6 cwt. In contrast to 1967, the spring of 1968 was dry and the summer wet. Deba Abed, which did not lodge, yielded more with N given in March, whereas Maris Badger, which lodged, yielded more with N given in May. However, both varieties yielded about 10 cwt/acre more straw from the March than from the May nitrogen dressings. (Widdowson, Penny and Flint)

TABLE 8

Effects of calcium nitrate on barley at Saxmundham

Yields of grain at 15% moisture content: cwt/acre

Without nitrogen	
Deba Abed	10·0
Maris Badger	13·7

Variety	0·6 cwt N/acre applied, March	0·6 cwt N/acre applied, May	1·2 cwt N/acre applied, March	1·2 cwt N/acre applied, May
Deba Abed	40·9	38·0	46·4	43·0
Maris Badger	35·1	36·5	32·1	34·4

Soils taken on 14 March from each plot of this experiment provided composite samples without formalin, with formalin in 1967 only, in 1968 only, and in 1967 and 1968. Ammonium-N and nitrate-N were measured in the fresh soils and after incubating for 24 days at 25° C. Formalin in 1968 increased the NH_4^+-N content of fresh soil slightly and decreased the NO_3^--N, thus decreasing the total mineral-N. The formalin applied in

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1967 increased total mineralisable-N (Δ min-N) by 10%, that applied in 1968 by 60%, and that applied in both years by more than 150%:

Formalin applied	Mineral-N in fresh soils NH_4^+-N	NO_3^--N	Total min-N
Mean of:		ppm N	
None and 1967 only	2·2	4·8	7·0
1967/8 and 1968 only	3·0	0·8	3·8

	No formalin	Formalin applied 1967	1968	1967/8
			ppm N	
Δ-min N	9·3	10·5	14·8	23·3

(Gasser and Widdowson)

Timothy and meadow fescue at Rothamsted. The experiment in which a seedbed drench of formalin was tested with and without four amounts of N (*Rothamsted Report for 1967*, p. 57) continued and two more cuts were taken. Formalin (applied in 1967) significantly increased yields at the first but not the second cut. Without formalin, nitrogen increased total yields (five cuts in two years) from 35·0 to 118·6 cwt dry grass/acre, with formalin from 46·0 to 127·7 cwt/acre. The total increase from the formalin ranged from 11·0 without N to 9·1 cwt/acre with most N, so formalin had proportionally most effect when N was not given.

Winter wheat at Rothamsted. In the experiments started in 1965 (*Rothamsted Report for 1965*, p. 49) on Little Knott and Pastures, formalin was applied in September 1967 in all combinations with all the previous applications. Cappelle Desprez wheat was sown in October. On Little Knott differences in growth between plots were large, but the improvements were mainly from nitrogen and little from formalin. On Pastures field both formalin and nitrogen improved growth. On Little Knott the wheat lodged only on the best plots, but on Pastures all the wheat lodged and where nitrogen was given it was quite flat.

TABLE 9

Effects of formalin and nitrogen on wheat

Yields of grain at 15% moisture content: cwt/acre

N applied cwt/acre	Little Knott Field Formalin in 1968 Without	With	Pastures Field Formalin in 1968 Without	With
0	18·9	19·8	28·4	23·3
0·5	33·1	36·8	31·0	24·3
1·0	35·5	38·4	25·1	22·1
1·5	37·1	34·5	23·8	20·3
Standard error	±2·29		±1·36 V* ±1·25 HI*	

* V—for vertical comparisons.
HI—for horizontal and interaction comparisons.

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Table 9 shows that on Little Knott formalin increased grain yields more with N than without, and its effect was roughly equal to that from one more increment of N. On this field all yields were larger than in 1967, even though this was the fourth consecutive wheat crop. On Pastures, formalin improved growth, but decreased yields, presumably because it made lodging worse. The largest yield (31·0 cwt/acre) came from 0·5 cwt N/acre without formalin and was 7·4 cwt less than the largest on Little Knott, a much less fertile field.

Table 10 shows the immediate and residual effects of formalin on each field each year. On Little Knott, applying it in February (1965 and 1966) benefited the first spring wheat. However, the year after it was applied it harmed both spring and winter wheat, though by amounts that varied from year to year. This harmful effect was temporary; the third and fourth wheat crops benefited slightly from the residual effects of the original application.

TABLE 10

Immediate and residual effects of formalin on spring (1965 and 1966) and winter wheat (1967 and 1968)

Yields of grain at 15% moisture content: cwt/acre

	Effect at harvest in			
	1965	1966	1967	1968
Formalin applied in		Little Knott Field		
1965	7·2	−3·3	0·6	1·5
1966	—	9·8	−12·3	3·3
1967*	—	—	1·5	−0·9
1968*	—	—	—	1·3
Standard error	±0·86	±0·90	±1·55	±1·62
		Pastures Field		
1965	0·6	0·3	−0·8	0·4
1966	—	1·5	−3·2	0·0
1967*	—	—	1·8	0·3
1968*	—	—	—	−4·6
Standard error	±1·17	±1·15	±1·23	±1·04

* Applied in September of previous year.

On Pastures field formalin had less visual effect and increased yields much less than on Little Knott, though in 1968 the fresh application greatly improved growth, but increased lodging and decreased yields. Here, residual effects from formalin were harmful only in 1967, and in the other years, and with subsequent wheat crops, they slightly increased yields. (Widdowson, Penny and Flint)

The efficiency of nitrogen fertilisers

Grass. Fresh dressings of 'Nitro-Chalk' were given to the meadow fescue and timothy in the experiment started last year at Saxmundham (*Rothamsted Report for 1967*, pp. 243–244) to measure response in yield to, and the efficiency of, N fertiliser. Some plots, fertilised at the end of February and again at the end of May, were cut on 28 May, 16 August and 23 October;

https://doi.org/10.23637/ERADOC-1-123

others, fertilised on four occasions between the end of February and mid-July, were cut five times between the beginning of May and the end of October. Yields and total N in the crops for the comparable twice-fertilised plots in 1967 and 1968 are in Table 11, which also includes the 1968 results from plots cut five times.

TABLE 11

Effects of N fertilisers on yield and nitrogen content of timothy–meadow fescue grass at Saxmundham

Treatment	Total N used in year lb/acre	Times/year fertilised	Times/year cut 1967	Times/year cut 1968	Total yield* in year cwt/acre 1967	Total yield* in year cwt/acre 1968	N in crop lb/acre 1967	N in crop lb/acre 1968	% of applied N recovered 1967	% of applied N recovered 1968
1	0	0	2	3	24·1	13·3	42	21	—	—
2	112	2	2	3	49·2	67·9	86	100	39	70
3	224	2	2	3	57·2	115·6	113	203	32	81
4	336	2	2	3	61·9	127·3	145	299	31	83
5	448	2	2	3	67·6	135·9	176	364	30	77
6	224	4	—	5	—	74·4	—	182	33	72
7	448	4	—	5	—	113·6	—	378	30	80
8	224	2	—	5	—	61·9	—	186	38	74
9	448	2	—	5	—	100·1	—	374	38	79

* Dry matter.

Yield without nitrogen fertiliser in 1968 was only half that of 1967, but all comparably treated plots given more than 112 lb N/acre yielded about twice as much as in 1968. On average about twice as much of the fertiliser-N was recovered in 1968 as in 1967; 70–80% recoveries of N in harvested grass are as large as we expect where N is being used very efficiently. The pairs of treatments 6 and 8, and 7 and 9, received the same amounts of nitrogen but whereas for 6 and 7 the fertiliser was divided into four equal dressings, given on 29 February, 1 May, 28 May and 12 July, for 8 and 9 it was divided into two (half was given on 29 February and half on 1 May). Total yields and N uptakes were almost identical from these two contrasted methods of fertilising, showing that little or no N was lost by leaching after 1 May. Last year's results suggested that much of the early dressings was lost by leaching during April and May (*Rothamsted Report for 1967*, pp. 246–248). (Cooke, Williams and Hamlyn)

Lucerne and clover. The large yields of grass at Saxmundham were matched by more than usual yields of second-year lucerne and red clover. The experiments started last year (*Rothamsted Report for 1967*, p. 243) were cut three times; the total yields and nitrogen contents were:

	Without K fertiliser	With 224 lb K_2O/acre
	Yields of dry matter, cwt/acre	
Red clover	71	74
Lucerne	100	111
	N in total yields, lb/acre	
Red clover	268	264
Lucerne	378	407

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Clover yielded 50% more than in 1967 and lucerne 100% more. The lucerne fixed two and a half times as much as N as in 1967. Lucerne given K fertiliser contained more N than the largest yield of grass in the experiment described in the previous section (378 lb N/acre). To get this amount of 'crude protein' in the grass, 440 lb/acre of N fertiliser was needed at a cost exceeding £20 per acre.

Wheat. Last year we reported small recoveries of fertiliser-N in the Intensive Wheat Experiment at Saxmundham. This year yields were larger and although responses to N were smaller, much more of the fertiliser was recovered. Yields of grain and the N contained in grain and straw together were:

	Crop sequence*	Fertiliser-N applied (lb/acre)					
		67	134	201	67	134	201
		Grain (cwt/acre)			N in crop (lb/acre)		
1	W, W, W	34·1	40·1	34·1	67	97	90
2	L, W, W	38·9	45·5	38·8	77	112	107
3	L, Be, W	46·3	44·1	40·0	113	118	121

(* L = ley, Be = beans, W = wheat)

The first increment of fertiliser-N increased yields in two of the three sequences, 46% of the dressing was recovered by the continuous wheat (sequence 1) and 52% by wheat in sequence 2. (Last year wheat following wheat recovered only a quarter of the fertiliser-N applied.) In 1968 the second increment of N diminished yields of wheat following wheat (and was wasted) as did both increments applied to wheat following beans. (Cooke, Williams and Hamlyn)

Nitrate in crops and drainage at Saxmundham. The field method of measuring nitrate in plants mentioned in last year's Report (p. 63) was used to follow changes in nitrate concentrations during spring and summer in wheat, barley, sugar beet, potatoes and grass. Losses of nitrates through the field drains were also measured. We hope that such measurements may indicate when top-dressings of N are needed, and show how to use N fertilisers more efficiently when there is much leaching.

Winter wheat. Nitrate was measured in sap from the lower stems of Cappelle Desprez wheat given different amounts of 'Nitro-Chalk'. Sap from plants without N fertiliser contained no nitrate at any time during May and those given 34 lb N/acre on 20 March contained 0–3 ppm. Plants given 112 lb N/acre in March (plus 56 lb N on 15 May) contained 875 ppm NO_3-N on 1 May, 100 on 8 May, 175 on 15 May and 139 on 19 May. The average response to the top-dressing in May was only 0·25 cwt/acre of grain, suggesting that plants containing >100 ppm of NO_3-N in the stems in mid-May had had enough fertiliser. Other plants were taken from the Intensive Wheat Experiment at Saxmundham on 12 June when the ears had emerged. None of the ears had more than 1 ppm NO_3-N: concentrations in different parts of stems were:

N applied lb/acre	Stem Lower	Middle	Upper
67	0	0	0
134	7	2	<1
202	250	200	<1

The grain yield was the same with 134 lb N/acre as with 202 lb.

Barley. Nitrate in sap from stems of Zephyr barley in Rotation I Experiment and an adjoining experiment was measured between 1 May and 2 July. Dressings of N fertiliser in mid-March supplied up to 112 lb N/acre, and some plots were given a second dressing of 56 lb N/acre on 29 May. Table 12 shows that plants given 56 lb N/acre had no nitrate in their stems by 10 June; those given 112 lb N contained considerable nitrate on 10 June but none on 2 July. Plants given 168 lb N still contained much nitrate on 2 July, but grain yields were not increased by giving more than 112 lb N/acre.

TABLE 12

Nitrate in stems of Zephyr barley at Saxmundham in 1968

Time (days)		N applied lb/acre 0	34	56	112	168
		ppm of NO_3-N in fresh material				
0	(1 May)	2	25	720	720	875
8		2	6	275	775	900
15		0	0	13	477	812
22		<1	<1	61	340	694
43		—	—	0·2	90	179
63	(2 July)	—	—	0·1	0·3	200

Sugar beet petioles were analysed between 13 June (when the singled crop was well established) and 26 September (when it was harvested). Table 13 shows that in mid-June all the plants sampled contained much NO_3-N, even those not given fertiliser-N, and that concentrations diminished on all plots with time. Beet given 112 lb N/acre still contained 400 ppm NO_3-N at the end of July, but very little by 15 August. Some plants given 112 lb N in spring and 56 lb N/acre on 25 July (making the maximum of 168 lb N shown in Table 13) had some nitrate in their petioles when harvested. This top dressing did not increase yield of sugar, but gave an extra 5 tons/acre of tops. (Sugar beet that gets too much nitrogen from soil or fertiliser can contain much more nitrate; very large plants on a headland adjacent to RI Experiment at Saxmundham contained up to 1000 ppm in leaf petioles and 100 ppm of NO_3-N in the crowns at harvest.) Measurements on beet receiving 168 lb N at the same time showed that petioles of outer leaves still had 13–26 ppm of NO_3-N when inner leaves and crown had none. As with wheat, the part of the plant taken for nitrate analysis affects results greatly.

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TABLE 13

Nitrate in sugar beet at Saxmundham in 1968

Time (days)		N applied, lb/acre 0	34	112	168
		ppm of NO_3-N in fresh material			
0	(13 June)	812	775	>1000	>1000
8		44	314	875	937
20		78	34	1000	942
29		2	15	500	560
43		2	4	400	400
64		0·1	1	0·8	320
71		0·2	1	2·9	322
84		0·5	3	2·5	242
90		0·5	0·5	1·5	62
106	(26 September)	0·4	0·5	0·6	19

Potatoes. The haulm was sampled between 22 May and 15 August, and could not be sampled later because of blight. 112 lb N/acre maintained 500 ppm of NO_3-N in sap of the stems until mid-August. With 56 lb N/acre, which sufficed for maximum yields, stems of plants still contained 22 ppm of NO_3-N in August.

Grass. Nitrate concentrations were measured in stems of grass harvested on 28 May from the experiments described on p. 47. Table 14 shows that the concentration of nitrate was related to the time the nitrogen was applied in relation to cutting. The largest concentration (>800 ppm) was in grass given 224 lb N/acre in February, was cut on 1 May and was immediately given a second dressing of 224 lb N. Comparing Tables 11 and 13 shows that grass, in contrast to the arable crops, responds greatly to extra N fertiliser even when the stems contain more than 100 ppm of NO_3-N at harvest.

TABLE 14

NO_3-N in grass at Saxmundham

N fertiliser: N applied lb/acre	Time applied	NO_3-N in stems ppm
0	All on 29 February	0·3
56		13
112		4
168		83
224		130
112	Half on 29 February and half on 1 May	92
224		201
448		828

Nitrate in drainage. The weekly rainfall at Saxmundham between January and September in excess of 0·4 in. during 1 week totalled 5·6 in. in 1967 and 10·8 in. in 1968. In 1967 about two thirds of this 'excess' rain fell between January and May, whereas in 1968 two-thirds fell between June and the end of September. Both years had the same number of weeks with this 'excess' rain. In 1967 the spring rain produced large drainage flows containing much nitrate (15–50 ppm); drains ran during

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the six weeks mid-April to the end of May, but not again until the middle of September. In 1968 less rain fell in spring; the drainage water had 3–90 ppm of nitrate, but the flow was irregular and lasted for only three weeks during late April and early May. In contrast to 1967, the drains ran at intervals through the summer and much nitrate was lost in the water, which contained from 5 to 56 ppm. The exceptionally large rainfall in September caused further leaching of nitrogen.

Other weather features. Relative humidities were greater, and sunshine, temperature and wind velocities less in 1968 than in 1967; all accentuated the effect of the wet summer. Moisture deficit (measured by evaporimeter) by 1 August was 7·0 in. in 1967 and only 1·3 in. in 1968. Soil was cooler during July–August in 1968 than in 1967; accumulated 'day degrees' above 42° F by the end of May were 640 in 1967 but only 604 in 1968. 'Day degrees' *below* 42° F by the end of May were 299 in 1967 and 511 in 1968.

Relationships between rainfall, other weather variables and crop growth defy any simple analysis. Leaching of nitrate by rain enough to cause drainage through the soil is a further complication. Leaching affects yield and lessens the value of N fertiliser in some seasons, such as 1967 with its wet spring. In 1968, with a drier spring but a very wet summer, there was no evidence that yields of crops given the most N were limited by N deficiency. In 1967, 168 lb N (68 lb as a late top-dressing) was needed by barley and sugar beet and the results suggested the crops would have responded to even more. In 1968, maximum yield of winter wheat, spring barley and sugar beet were obtained with 112 lb N/acre applied in March, and late top-dressings that increased the amounts given to 168 lb N did not increase yields.

The large amounts of NO_3-N lost in drainage water at Saxmundham during the summer and autumn of 1968 were unusual, but seem not to to have lessened yields of well-fertilised crops. They may make responses to N fertiliser in 1969 much larger than usual, because soils and subsoils have lost their reserves of nitrate. (Williams)

N and K fertilisers and the composition of ryegrass

Effects on free amino acids. Last year's Report (p. 50) gave preliminary results on the distribution of some free amino acids in Italian ryegrass grown in K-deficient soil with different fertilisers. Table 15 shows the average effects of increasing K and N dressings on the concentration of free amino acids in the leaves of the second cut. Results are also given for glutamine, asparagine and ammonia, large quantities of which accumulate in all K-deficient plants. Increasing the K usually decreased the free amino acids at all amounts of N. β-alanine usually occured (29–94 ppm) in K-deficient plants only; cystine was not found and only traces of methionine were detected. Putrescine, and its precursor agmatine, which occur in K-deficient barley leaves and have been reported in other cereals, are being looked for in the second cut of grass. (Nowakowski with Byers, Biochemistry Department)

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TABLE 15

Effects of potassium and nitrogen on free amino acids in Italian ryegrass

	ppm in soil						
	Potassium				Nitrogen		
	0	60	120	240	40	80	160
	ppm amino acid in dry leaf						
Aspartic acid	194	132	80	97	64	92	222
Asparagine	3123	1154	944	271	552	665	2902
Serine	850	429	259	169	156	287	838
Glutamic acid	548	512	380	409	277	348	763
Glutamine	4955	2225	828	167	671	1603	3882
Proline	619	297	144	146	79	206	619
Glycine	75	43	28	26	25	33	72
Alanine	460	342	306	267	228	312	492
Valine	688	365	175	77	109	294	577
iso-Leucine	300	176	79	39	51	136	259
Leucine	224	157	80	45	60	123	198
Tyrosine	107	81	40	30	25	52	117
Phenylalanine	347	192	97	57	56	139	325
4-amino-*n*-butyric acid	432	210	169	159	176	242	310
Lysine	381	265	120	50	60	170	382
Histidine	278	154	65	29	32	109	253
Arginine	159	103	39	24	27	54	163
Ammonia (as NH_4^+)	1207	422	234	161	239	555	724

Effects on protein-N content. We reported last year (p. 50) preliminary results that K fertiliser increased the protein-N in ryegrass grown in pots. This experiment has now been completed and Table 16 shows how K affected the composition of two cuts of ryegrass. Increasing K up to 120 ppm in soil increased the protein-N (expressed as % of total N) of the first cut with each amount of N, but the largest K dressing decreased it. The protein-N of the second cut was increased by all K dressings given at the start of the experiment. (Nowakowski)

TABLE 16

Effects of potassium and nitrogen on the protein-N in Italian ryegrass

Fertiliser (expressed as ppm N or K in soil)	Protein-N (expressed as % of total N)	
	1st cut	2nd cut
N		
40	87·9	88·0
80	85·8	85·5
160	80·0	79·8
K		
0	80·3	76·1
60	85·8	83·8
120	89·5	88·3
240	82·7	89·6

Magnesium and other nutrient cations

In 1967 wheat and potatoes growing at Woburn in an experiment comparing different crop sequences on yield of wheat showed symptoms of magnesium deficiency. The experiment was on some plots of the old Permanent Wheat Experiment, all of which had been limed to pH 6·5 with

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limestone containing only 0·4% Mg. In autumn 1967, half of each plot was given a large dressing of magnesium sulphate (100 lb/acre Mg), which clearly improved both the colour and vigour of the wheat in May. % Mg in the dry matter of leaves was increased by both N and Mg. Grain and straw yields were increased by Mg, but less than expected from the early appearance of the crop (Table 17).

TABLE 17

Effects of N and Mg on wheat

Woburn Intensive Cereal Experiment (mean of all crop sequences)

Mg lb/acre		N lb/acre 56	112	168	224	Mean
		cwt/acre grain at 85% dry matter				
0		20·3	23·7	25·8	24·5	23·5
100		19·9	25·2	27·1	25·9	24·6
	Standard errors		±0·82			±0·29
		cwt/acre straw at 85% dry matter				
0		36·5	33·2	27·3	24·3	30·3
100		37·2	35·1	27·7	25·8	31·5
	Standard errors		±2·00			±0·43
		% Mg in leaf dry matter in May 1968				
0		0·074	0·088	0·097	0·098	0·089
100		0·115	0·139	0·140	0·141	0·134

Most of the variation in yield in this experiment was related to differences in take-all attack in the different sequences (pp. 138–139). Take-all seemed to influence the leaf analyses. The percentages of N, K, Ca and Mg were smaller in the third successive wheat after the two-year break of ley and potatoes than in the crops grown one and two years after the break, but there was a highly significant linear regression between total cation concentration and % nitrogen in the leaves from all plots of the experiment. This suggests that take-all affected uptake of all nutrients similarly and that there is no special relationship between pathogen attack and magnesium deficiency as was suspected from last year's observations. Topsoils and subsoils were analysed after harvesting the cereals. The added Mg was fully recovered as exchangeable Mg from the topsoil (0–9 in.). In plots not given magnesium, exchangeable Mg was related to the treatments of the old plots on which the new experiment was superimposed (Table 18). All plots had similar pH values. The greater yields of potatoes and leys on the barley site than on the wheat site (*Rothamsted Report for 1966*, p. 267) may depend, at least in part, on these differences in Mg. (Bolton)

A grass/clover ley, the first of two break crops in this experiment, receives only 45 lb of N/acre (to the seedbed). The plots were split in 1968, and half of each was given 100 lb/acre of magnesium. Yields of dry matter at the first cut (mostly ryegrass) were not significantly increased by magnesium, but were at the second (mostly clover), from 10·3 to 14·3 (±0·38) cwt/acre. On the plots of the old Permanent Wheat Experiment given ammonium sulphate from 1879–1927, clover established only on the

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TABLE 18

Effects of treatments between 1876 and 1927 on exchangeable Mg in soil of Intensive Cereal Experiment at Woburn

Manuring 1876–1927	Wheat site 0–9 in.	Wheat site 9–18 in.	Barley site 0–9 in.	Barley site 9–18 in.
	ppm of exchangeable Mg			
None	11	15	14	23
Ammonium sulphate	8	12	12	24
Sodium nitrate	12	21	16	24

subplots with magnesium, and the subplots with and without added Mg differed spectacularly after the second cut, emphasising that different species need different amounts of magnesium. (Bolton)

In another experiment in the same field residual effects on ryegrass were measured of magnesium, potassium and sodium fertilisers added during the previous eight years. Exchangeable magnesium in the topsoil ranged from 14 to 140 ppm and potassium from 29 to 85 ppm before the grass was sown in August 1967. Yields of dry matter were increased significantly by residues from potassium and sodium fertiliser, but not by magnesium. (Bolton and Penny)

Extraction of potassium from soils by exchange resins

Suspensions of H^+-saturated resins shaken continuously with soils are at pH 3 or less and remove as much K as strong acids; the extracted K has little relevance to what is taken up by plants. Ca-saturated resins remove much less K than exchanges with NH_4^+- or Ca^{2+}-solutions and equilibrium is reached after a day. A 'successive equilibrium' method of extracting K by Ca^{2+}-resin exchange was developed to simulate K that is taken up by plants, which after entering the roots moves to the tops. Fresh batches of Ca-saturated resin were equilibrated with soil for increasing times so that the K adsorbed by the resin during each period did not exceed 1% of the exchange capacity of the resin.

Extracting eight Rothamsted soils with contrasted manurial histories showed that a rapid exchange was completed in from $1\frac{1}{2}$ to 3 days. Afterwards potassium was slowly released, for at least 66 days, in amounts directly proportional to $(\text{time})^{\frac{1}{2}}$. This must depend on diffusion within the soil particles because diffusion into the *resin* cannot alter the rate K is released.

The K rapidly-exchanged by resin was linearly related to *M* ammonium-acetate-exchangeable K (and the amounts were similar). The rapid and slow releases to Ca-resin were linearly related to rates of uptake by plants grown for long periods in pots under glass. This suggests that K^+ ions are transferred from the surface of soil particles by exchange very quickly, and that, when surface exchange is complete, diffusion of K within the soil particle controls uptake by resin or crop roots. During this stage, exchangeable K and originally non-exchangeable K are released to the crop at about one-twentieth and one-half, respectively, of the rates that they were released to the resin. The time needed for roots to grow to new

https://doi.org/10.23637/ERADOC-1-123

surfaces must account for these differences and the actual speed of root growth in an experiment will modify these factors. (Talibudeen and Rajendran)

Sulphur

Sulphur is an essential nutrient, required by plants in about the same weight as P. Coal, oil and unpurified natural gas contain much S and in most industrial countries burning these fuels puts enough sulphur in the air and rain to provide for crops; sulphur is also supplied by sulphates used as fertilisers (e.g. calcium sulphate in ordinary superphosphate). The cleaning of combustion gases to make the air purer, and the change to more concentrated fertilisers that contain little or no S, increase the possibility of responses to sulphur. What we think are the first effects in England of applying sulphur to soil in field experiments were obtained with conifer seedlings and radishes at Wareham, Dorset.

Sitka spruce. In 1965 Sitka spruce (*Picea sitchensis*) seedlings grown in very acid soil (pH in 0·01*M* $CaCl_2$ 3·3–3·5) at Wareham gave height responses to graded additions of calcium sulphate (*Rothamsted Report for 1965*, p. 62), which were attributed to calcium acting as a nutrient. In the same experiment, improvement in seedling colour also closely followed the amounts of calcium sulphate given, and it was suspected that the pale green of the untreated seedlings was associated with sulphur deficiency. Later results from several small trials with Sitka spruce seedlings testing calcium sulphate, sodium sulphate and calcium carbonate, showed that calcium improved growth but not colour, whereas sulphur improved colour but not growth.

In 1967, healthy green seedlings grown with potassic superphosphate (a mixture of 90% single and 10% triple superphosphate plus KCl) supplying 14 g S/m^2 contained 0·18% sulphur in needle dry matter, whereas needles from pale plants on plots with sulphur-free fertilisers contained 0·09% sulphur; needles from plots with similar fertilisers but with 14 g S/m^2 contained between 0·10% and 0·16% when S was supplied as sodium sulphate and 0·16% S when calcium sulphate was given. This agrees fairly well with the values of <0·13% S given by Ingestad as indicating deficiency and 0·13–0·18% S as an intermediate range for Norway spruce (*Picea abies*) grown in solution culture (*Meddn. St. SkogsforskInst.* (1962), **51**, No. 7, 150 pp.). The only published reference to sulphur deficiency in conifers in Britain seems to be the transient yellowing of Corsican Pine (*Pinus nigra* var. *calabrica*) observed by Binns and Keay on 'no sulphur' plots on the Culbin sand dunes in Scotland (*Rep. For. Res., Lond. for 1962*, p. 87).

To elucidate further the effects of S and Ca, Sitka spruce seedlings treated with Ca- and S-free fertilisers (consisting of magnesium ammonium phosphate, potassium metaphosphate and top-dressings of either urea or ammonium nitrate) were compared with those given additional calcium carbonate, sodium sulphate, calcium sulphate ($CaSO_4.\frac{1}{2}H_2O$) or flowers of sulphur. The sulphur concentrations in seedling needles (Table 19) agreed well with earlier results and ran parallel to the colour scores,

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except that the slight improvement from sodium sulphate was not reflected in larger % S. Heights of seedlings at the end of the season confirmed the vigour scores, which showed that calcium (whether applied as calcium carbonate or as calcium sulphate) but not sulphur improved growth. (Benzian, Bolton and Freeman)

TABLE 19

Effect of sulphur and calcium on Sitka spruce seedlings, Wareham 1968

Treatments	applied (g/m²) Ca	S	August Colour score*	Vigour score	% S (needles)	End-of-season Height (cm)	pH ($CaCl_2$)
None	—	—	2·4	2·1	0·092	9·2	3·2
$CaCO_3$	24	—	2·0	2·8	0·082	9·9	3·5
Na_2SO_4	—	19	3·3	1·8	0·096	9·2	3·2
$CaSO_4.\frac{1}{2}H_2O$	24	19	4·2	3·0	0·170	10·3	3·3
Sulphur	—	19	5·0	2·2	0·196	7·0	3·1
			Standard errors		±0·0048	±0·15	±0·03

* Largest value = darkest green.

Many seedlings on plots treated with flowers of sulphur and a few seedlings on those with calcium sulphate (all with basal ammonium nitrate) had the characteristic tip-burn symptoms of copper deficiency. The tops of these plants contained only about 1 ppm Cu (in dry matter) whereas symtom-free seedling tops on calcium sulphate plots contained 3 ppm. These values agree fairly well with those of Benzian and Warren (*Nature*, *Lond.*, (1956), **178**, 864). (Benzian, with Hill, Biochemistry Department)

Radish and lupin. These species were expected to need more sulphur than Sitka spruce, and were used as test crops in two small trials at Wareham in 1968 on plots exhausted by 15 years of continuous cropping without fertilisers. Sulphur-free basal NPKMg fertilisers were used. Table 20 shows that 19 g/m² of elemental sulphur increased dry matter yields of the first radish crop (planted in mid-May and harvested 6 weeks after) by about 14%. This seems to be the first statistically significant yield response by any crop in the U.K. to sulphur applied in the field. Plants from the untreated plot contained only 0·22% S, much less than is usual in brassicae. A second radish crop grew badly on the plots given sulphur, possibly because the sandy soil had become very acid. However, a third crop planted in mid-August after liming, also yielded less dry matter on the sulphur-treated than on untreated plots; the radishes from this planting on the untreated plots contained more sulphur than those of the first planting on treated plots, showing that some sulphur had become available to the plants during the summer either from rain, the atmosphere or by mineralisation of organic-S.

Yellow lupins planted in May and harvested in late August yielded less on the sulphur-treated than on the untreated plots, again possibly because of acidity (soil pH measured in water was 4·1 in treated and 4·7 in untreated plots after cropping). (Bolton and Benzian)

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TABLE 20

Sulphur and yields and composition of radishes and lupins

S applied g/m²	Radish 1st crop Yield*	%S	Radish 3rd crop Yield*	%S	Lupin Yield*	%S
0	202	0·22	191	0·76	519	0·22
19	231	0·73	145	0·96	386	0·45
Standard errors	±4·1	±0·046	±8·6	±0·060	±34·4	±0·022

* Yields as g dry matter/m².

Sulphur in air. As a preliminary to studying sulphur balance in parts of Africa where S is deficient, a radioactive dilution technique (modified from Olsen, R. A., *Soil Sci.* (1957), **84**, 107) was used to measure how much S was absorbed from the air by leaves of mustard (*Sinapis alba*) grown in a glasshouse. The plants were grown for 6 weeks in a nutrient solution containing 30 ppm sulphur, labelled with S^{35}, and harvested when they had finished flowering. After measuring sulphur in the plant tops and its specific activity (S/A), the percentage of total sulphur in the tops obtained from air was calculated from:

$$\% \text{ S in plant from atmosphere} = 100 - \left(\frac{\text{S/A plant} \times 100}{\text{S/A nutrient soln.}}\right)$$

Half of the S in the plants came from the air; the results were very consistent, and for 9 pots ranged only from 47% to 50%. The mean concentrations of S in air was 25 μg S/m³ during the experiment. (Bromfield)

Sulphate leaching in latosols. The results of lysimeter experiments at the Rubber Research Institute of Malaya, to measure how much sulphate from ammonium sulphate was leached through the profile of a latosol, were compared with leaching rates calculated using a model system. The model profile was divided into 'plates', each of which held the volume of water that was added every 3 days in the experiments. Adsorption of sulphate in each plate was calculated from a Langmuir adsorption isotherm derived from the experimental results. A computer programme, written to calculate the rate sulphate should move down the profile, took into account sulphate present in the soil before leaching, and the sulphate added as ammonium sulphate was assumed to dissolve in the first amount of water added to the soil surface. Calculated and observed rates of movement agreed well. Also the shapes of 'chromatogram' patterns of sulphate in the 'plates' down the profile resembled those observed in lysimeters removed at intervals during the experiments. (Bolton with Bicknell, Computer Department)

Herbicides

Selective herbicides that kill weeds in cereal crops were introduced about 25 years ago and since then have been developed to kill weeds in other crops. Other herbicides (such as simazine) are toxic to most plants, but are applied before the crop emerges and retained in the surface soil where they kill shallow-rooting weeds but not deeper-rooted crops. Other generally

https://doi.org/10.23637/ERADOC-1-123

toxic materials, such as paraquat, kill the green parts of all plants, but are said to be inactive in soil. Residues of various herbicides in soil can damage following crops and knowledge of their solubility and decomposition is important.

Damage caused by overdoses of simazine at Rothamsted and work on the contaminated soils, was described in the *Rothamsted Report for 1966* (p. 60). Beans on Barnfield in 1967 and 1968, and on Broadbalk in 1968, were damaged by simazine used as recommended. The damage depended on past manuring, and was least on the FYM plots. In experiments where the crops are treated with persistent herbicides the possibility that these will interact with fertiliser treatment should always be considered, and comparisons of effects of organic manures and fertilisers are especially liable to such complications.

Simazine and beans. Effects of simazine on beans on Broadbalk are described elsewhere (p. 260). Yields were 42 cwt/acre on the FYM plot and 37 cwt on the plot given N plus 'minerals' (NPKNaMg), when the beans showed signs of herbicide damage. Hence, it is not sure whether the extra 5 cwt/acre on the FYM plot reflected nutritional benefits, or physical effects on soil structure or were due to FYM protecting the beans from the herbicide. On other plots where the crops grew slowly because they lacked K, damage was greater. On Barnfield in 1968 beans were grown with and without simazine and gave these yields on differently manured plots:

Manuring	Without simazine	With simazine
	cwt/acre of beans	
None	25·7	7·6
PKNaMg	30·8	16·7
FYM + PK	31·9	29·6

Assuming that all the simazine remains in the surface inch of soil (weighing $0{\cdot}3 \times 10^6$ lb/acre), J. D. H. Williams' (*Weed Res.* (1968), **8**, 327) measurements of adsorption of simazine by Rothamsted soils (below) were used to estimate soil/water partition coefficients K_D for plots of Barnfield given PKNaMg fertilisers or FYM:

Annual treatments	Organic carbon in soil %	K_D
FYM	2·40	1·2
PKNaMg	1·09	0·4

As soil moisture diminishes, simazine in the soil solution becomes more concentrated. Averages of the usual moisture contents show that Barnfield soil solution may contain twice as much simazine (5 ppm) in fertiliser plots as on the FYM plot. Simazine is strongly absorbed by soil organic matter but not by clay. Recommendations for using simazine to control weeds on beans, warn that damage may occur on light sandy soils; it

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seems that soils of other types containing little organic matter may also absorb too little simazine to prevent damage. (Briggs)

Methods of breakdown. We are trying to discover how chemical structure, microbial activity and absorption affect persistence in soils to establish principles that govern methods and rates by which a herbicide and its metabolites break down, mostly using substituted ureas and anilines. The urea group is being developed for new uses in arable farming; earlier materials, monuron and diuron, have been well studied but there is little information about the breakdown of the newer ones. More than a third of current herbicides are derived from anilines or nitro-compounds that reduce to anilines in soil, and the materials used during a rotation of arable crops may produce a continuous supply of aniline derivatives. For example metoxuron and barban may be used for cereals, linuron and related products for potatoes, various carbamates for sugar beet, monolinuron and dinoseb for beans, and DNOC and trifluralin for a range of crops.

Adsorption isotherms were measured for several herbicides in 4 soils from Barnfield and the Rothamsted Ley-Arable experiments containing from 0·6% to 2·5% organic carbon. Adsorption of linuron was proportional to % soil organic matter and, with each soil, the isotherm was curved (as Graham-Bryce found for the adsorption of disulfoton (*Rothamsted Report for 1966*, p. 177)). Of six substituted ureas studied, fluometuron and monuron were least adsorbed, chlorbromuron and linuron most, and diuron and metobromuron were intermediate. All relationships were curvilinear. Of substituted anilines tested with Fosters field soil (1·5% organic carbon), diphenylamine was most and 3·4 dichloro-aniline least adsorbed. Results to date suggest that the adsorption of ureas increases with increasing deactivation of the phenyl ring. The products identified after aromatic amines were incubated for 21 days with Barnfield soils containing little organic matter suggest they were formed by an oxidation process followed by coupling with unchanged amine. (Briggs)

Apparatus and methods

Measuring ammonia-N in plant extracts. The steam distillation procedure developed by Bremner (*Rothamsted Report for 1959*, p. 59) to measure ammonium-N in plant extracts gave results agreeing closely with those obtained by distillation under reduced pressure below 40° C (*Ind. Engng Chem. analyt. Edn* (1935), 7, 152). However, it does so only with plant extracts containing little glutamine; when extracts are rich in glutamine it gives much more ammonia. Tests with freshly prepared glutamine standard solution showed that 4·8% of glutamine amide-N was liberated as ammonia-N during the steam distillation whereas only 0·70% was liberated during distillation under reduced pressure. Many plant extracts are rich in glutamine, and with these the steam distillation method will give erroneous results for both ammonia and glutamine. (Nowakowski)

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Variations in %N in fractions of ground plant material. Irregular results were encountered when 100 mg replicates of Sitka spruce seedlings, kale or grain were used to measure N with the 'Coleman Nitrogen Analyzer', and we suggested finer grinding might remedy this (*Rothamsted Report for 1966*, p. 61). Sitka spruce seedling tops were ground in a Christy & Norris mill fitted with a 1·0 mm screen; sub-samples of this material were ground in a ball mill to pass sieves of increasing fineness. Ten determinations of %N were made on each sample (average 1·34% N) and the calculated coefficients of variation were:

sieve size		
<1·0 mm	<0·5 mm	<60 mesh
7·6%	3·9%	2·2%

The particle size distribution of the material from the Christy & Norris mill was also determined together with %N in each fraction; the results were:

	sieve size			
	>1·0 mm	1·0–0·5 mm	0·5–0·25 mm	60 mesh <0·25 mm
Per cent of whole in each fraction	1·00	41·00	26·00	32·00
%N in each fraction	1·04	1·06	1·36	1·68

(Hamlyn)

Carbon in soils. Attempts are being made to improve equipment for measuring carbon in soils by dry combustion, and two methods of sampling the products of combustion were developed: (1) Combustion is in a closed system in an atmosphere of helium. After combustion the products are swept out by helium carrier gas through a copper tube. At a prescribed time, this tube is transferred to a gas chromatograph and the CO_2 measured. (2) Combustion is in a stream of helium and the products pass through a proportioning device that rejects a selected fraction to the atmosphere. The remainder passes through a chromatograph column of silica gel in which the CO_2 is trapped. When combustion is complete, this column is transferred to the chromatograph and the CO_2 measured. Both methods are satisfactory and give reproducible results when measured volumes of dry CO_2 are injected into the combustion tube.

Recovery of C from combustion of organic compounds, such as sucrose, is small, ranging from 30% to 90%, and several oxidising agents (singly and in mixtures) were tried. CuO alone most consistently gave the largest recovery. It now seems that the filling of silver wool and copper turnings used for the combustion tube was unsatisfactory. Recoveries are greatly improved when part of the copper turnings is replaced by granulated CuO and the gases are sampled by the second method. (Smith)

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Staff and visiting workers

P. D. Salt and Marie Blakemore left and G. G. Briggs was appointed.

Visiting workers included Dr. R. Al-Badrawy (Iraq), Dr. C. A. I. Goring (USA), Dr. A. Islam (Pakistan), Mr L. Lawal (Nigeria), Dr. O. G. Oniani (USSR), Mr. S. Sivasubramaniam (Ceylon), and Dr. E. D. Spratt (Canada).

G. W. Cooke visited research institutes and universities in Czechoslovakia at the invitation of the Czechoslovak Ministry of Agriculture and with the help of a travel grant from the British Council. J. K. R. Gasser visited the Rubber Research Institute of Malaya from 23–26 July at the invitation of the Director; he attended the 9th International Congress of Soil Science at Adelaide and visited research institutes in Australia with the help of a grant from the Agricultural Research Council. G. E. G. Mattingly was invited to join a Royal Society Committee, under the Chairmanship of Sir Joseph Hutchinson, to advise on the organisation and the research programmes of agricultural research institutes in Ghana. F. V. Widdowson was given a grant by the A.R.C. to attend the Second International Conference on Mechanisation of Field Experiments (I.A.M.F.E.) held in Braunschweig (Germany) in July.

E. D. Spratt was awarded the Ph.D. degree of London University.

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