ROTHAMSTED RESEARCH

Rothamsted Report for 1966

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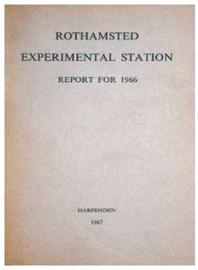

Chemistry Department

G. W. Cooke

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CHEMISTRY DEPARTMENT

G. W. COOKE

T. M. Addiscott was appointed and J. D. H. Williams joined the staff temporarily. O. Talibudeen was seconded to work for a year at the Rubber Research Institute in Malaysia. Visiting workers included Mr. S. A. Freminot (Seychelles), Mr. R. G. French (Australia), Dr. J. Hagin (Israel), Mr. Glenn Raines (U.S.A.), Mr. T. C. Sim (Sarawak), Mr. E. D. Spratt (Canada) and Mr. M. A. P. Thorburn.

G. W. Cooke attended the Eighth Congress of the International Potash Institute in Brussels at the invitation of the Institute. He was a member of the United Kingdom delegation at a Symposium on Economic Aspects of the Use of Fertilisers, arranged by E.C.E. and F.A.O. in Geneva, and Chairman of the meetings. B. Benzian, J. Bolton, G. E. G. Mattingly and J. D. H. Williams attended the Meeting of Commissions II and IV of the International Soil Science Society in Aberdeen.

B. S. Coulter, J. Deist and M. D. Webber were awarded the Ph.D. degree of London University, and J. D. H. Williams the Ph.D. degree of the University of Canterbury.

Soil properties and fertility

Root development. The experiments at Wareham nursery (*Rothamsted Report* for 1965, p. 39) were continued with ryegrass replacing Norway spruce. Sitka spruce, Japanese larch and ryegrass were grown in yard-square plots on two sites. One set of plots was double dug by removing the topsoil, then the A_2 horizon, when the humus–iron pan was broken and the horizons replaced in their original order; the replicate set of plots was single dug. The roots of each species on each plot were excavated on a "nail board" and washed. Although Japanese larch has a strong tap root, double digging made little difference to it, and the root grew sideways at the top of the A_2 horizon. Sitka-spruce roots penetrated a little deeper into the A_2 with double than with single digging; roots in the double- but not the single-dug soils had thickened ends. Grass produced more roots, and double digging promoted much growth in the A_2 horizon, which also contained some roots after the single digging.

Roots do not penetrate the A_2 horizon of these podzolic soils easily because the sand grains pack so that the pore spaces are too small for the rather coarse roots of forest seedlings to enter, though large enough for the finer grass roots. The A_2 horizon resettles quickly after double digging, and the main use of this operation for tree seedlings is breaking the humus–iron pan and improving drainage; it does not improve root penetration.

An experiment at Broom's Barn (with P. Draycott) with sugar beet tested factorial combinations of four spacings, four nitrogen dressings and irrigation. In four selected plots ^{32}P was placed at 1, 2, 3 and 4 ft; leaf

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samples from plants were strongly radioactive at only 26 out of 128 points labelled (8 replicates of 4 depths in 4 treatments). In each plot some roots absorbed ^{32}P placed 4 ft deep. Closely spaced, nitrogen-fertilised plants took up much more from 1 ft deep than did widely spaced or closely spaced plants without nitrogen. (J. K. Coulter)

Experiments with soil conditioners. Some of the soil on the old Permanent Wheat and Barley experiment sites on Stackyard Field at Woburn, with very little organic matter (0·5–0·6% organic C), has been used since 1963 for a microplot experiment testing the cumulative effects of adding peat. Several methods of application and four amounts of peat have been tested, and by 1966 there had been four annual dressings; each spring the cultivations (done by hand) thoroughly mixed previously applied peat with soil. Globe beet was grown in 1963 and 1965. Peat increased the number of seedlings by 30%; in 1963 the thinned plant population was not maximal and was not improved by peat, but in 1965 it was maximal with peat and 10% fewer without. Peat did not affect establishment of the 1964 carrots or the 1966 potatoes, but increased yields of each crop (in Table 1), although only carrots responded well to the large amounts. These gains

TABLE 1

Effects of peat on yields of globe beet, carrots and early potatoes at Woburn in 1963–66

(tons/acre)

Peat added each year (cwt dry matter/acre)	1963 globe beet	1964 main crop carrots	1965 globe beet	1966 early potatoes
0	5·6	15·6	15·2	8·8
62·5	7·4	16·0	16·4	10·2
125·0	7·1	16·9	16·5	10·0
187·5	7·5	17·1	16·5	10·6

from peat are not spectacular, but as all cultivations were by hand, the seed-beds were not compacted by tractors and implements, and effects might have been larger with mechanical cultivations, which will be tested in future. (Johnston)

At Saxmundham a microplot experiment tests additions (amounting to 5% of the volume of soil) of peat, FYM, "Krilium", a light polystyrene waste, and finely and coarsely granulated samples of sintered "fly ash" (from power-station furnaces) to increase total pore space and water-holding capacity of the soil. The "rigid" materials that did not decompose had largest effects. Digging in 0·5 ton/acre of polystyrene waste, 17 tons/acre of peat or about 40 tons/acre of "fly ash" similarly increased pore space by 4–5%. 10 cwt/acre of the active ingredient of "Krilium" as a surface dressing increased porosity by 2·4%. Soil moisture was measured throughout the season by nylon/stainless-steel resistance units. All treatments increased the moisture-holding capacity of the soil, from a mean moisture content of 19% with untreated soil to 21½% with fly ash, 23% with peat and polystyrene and 25% with FYM and "Krilium". "Kri-

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lium" preserved the surface tilth established by cultivating in spring; the other materials did not, and slaking was as severe on treated as on untreated plots.

Physical soil problems at Saxmundham are largely because the impervious subsoil does not allow quick drainage; the soil holds little water, so is quickly saturated by rain, and when waterlogged is liable to surface slaking, leading to run off, because of its mechanical instability. Materials intended to improve physical properties should increase stability, pore space at depth, water-holding capacity and drainage. Several of those tested improved water relationships, but only "Krilium" prevented surface slaking. (R. J. B. Williams)

Experiments with organic manures

Market-garden crops at Woburn. Microplot experiments at Woburn from 1960 to 1964 compared farmyard manure (FYM) and fertilisers on new sites each year to avoid physical effects from accumulating organic matter. With optimum amounts of nutrients, fertilisers and FYM gave the same yields of globe beet, maincrop carrots and sugar beet. In the experiment started in 1942 at Woburn on manuring market-garden crops the amounts of P and K applied as fertilisers were less than those in the FYM; more P and K accumulated in soils of the FYM plots, so that the better yields on these plots could not be ascribed solely to the beneficial effects of organic matter. Since 1961 fertilisers have been increased, and recent yields were given in *Rothamsted Report* for 1964, p. 248. Leeks planted at the same density on all plots yielded only 0·5 ton/acre more with FYM than with fertilisers (previously FYM produced 1·5 tons more). Early carrots in 1963 yielded 6·0 tons with FYM (these plots had more plants) and only 3·8 tons/acre with NPK fertilisers. In 1964, when populations of carrots were the same, FYM gave 13·9 tons and NPK fertilisers 13·4 tons/acre, but in 1965 plant numbers and yields were again larger with FYM. Globe beet have often germinated unevenly and slowly on the fertiliser plots; FYM has given quicker growth, a more uniform plant and larger yield. These gains on the plots continuously treated with FYM for 20 years may have been from improvements in soil structure, from nitrogen released from the extra organic matter at times that suited the crops better or from the extra P and K contained in the FYM-treated soils.

An experiment to test some of these factors was started using microplots within some of the large plots of the old experiment, globe beet were tested in 1965, carrots in 1966. Peat was tested at 12·5 tons dry matter/acre; the test of 10 and 20 tons/acre of FYM was continued on some plots but not on others where FYM residues were tested. Appropriate tests of extra N, P and K fertilisers were also made. The seed was dressed with fungicide, and all work was done by hand to avoid compacting the soil by wheeled implements. Conditions in the spring favoured establishing a good plant of red beet; germination on the fertiliser plots was good, but peat increased number and weight of seedlings:

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	Number of seedlings per plot	Average dry weight (g/seedling)
Fertiliser plots		
Without peat	1,219	0·028
With peat	1,327	0·038
FYM plots		
Residual effects only	1,341	0·040
With fresh dressings	1,337	0·044

A satisfactory stand of carrots was established, but they grew better through most of the season on the FYM than on the fertiliser plots.

Table 2 compares the responses of red beet and carrots to fertilisers and FYM. In 1965 the beet on both fertiliser plots and FYM plots responded

TABLE 2

Effects of fertilisers and farmyard manure on the yields of globe beet and carrots in the Market Garden Experiment at Woburn, 1965, 1966

1965 globe beet (tons/acre)

	Fertilised plots			
	Without peat		With peat	
PK fertiliser	P1K1	P2K2	P1K1	P2K2
N fertiliser (lb/acre)				
0	4·2	5·9	4·6	8·6
200	12·9	13·6	14·2	15·9

	FYM-treated plots			
	Residues only		Residues + fresh dressing	
FYM (tons/acre)	10	20	10	20
N fertiliser (lb/acre)				
0	8·6	13·0	12·1	15·6
200	16·0	16·7	15·8	18·3

1966 early carrots (tons/acre)

	Fertilised plots			
	Without peat		With peat	
PK fertiliser	P1K1	P2K2	P1K1	P2K2
N fertiliser (lb/acre)				
50	14·4	17·8	15·4	18·3
100	17·4	21·4	18·6	21·2

	FYM-treated plots			
	Residues only		Residues + fresh dressing	
FYM (tons/acre)	10	20	10	20
N fertiliser (lb/acre)				
0	18·4	19·2	23·0	24·3
50	20·2	21·3	23·2	25·2

Rates/acre

P1K1	73 lb P	139 lb K
P2K2	147 lb P	279 lb K

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well to all amounts of N, and the shapes of the response curves showed maximum yield had not reached. The 1966 carrots responded to N with PK fertilisers, but not with fresh FYM, and 25 tons/acre seemed to be the maximum yield. The double dressings of P (147 lb/acre) and K (279 lb/acre) produced larger yields of both crops than the single dressing, and the double dressing of FYM produced more than the single, whether tested as a fresh dressing plus the residual effect of many previous dressings or as the residual effect alone. Giving peat to the fertiliser plots increased the yields; the increase with carrots was larger with the single dressing of PK, with beet it was larger with the double dressing.

The combined immediate and residual effect of 10 tons/acre of FYM was a yield of globe beet similar to that of plots treated with the double dressing of PK fertiliser *and* with peat, both sets of plots were given the same amount of nitrogen; the plot given 20 tons/acre of FYM produced this yield without extra fertiliser nitrogen. The residual effects of FYM plus extra nitrogen produced carrot yields similar to those from the double dressing of NPK fertiliser. A fresh dressing of FYM, even the single dressing, produced larger carrot yields than were obtained with fertilisers.

The results in 1965 and 1966 suggest that for globe beet and carrots at Woburn the residual effects of repeated annual dressings of 20 tons/acre of FYM can be equalled by suitable fertiliser dressings as soon as FYM is no longer given, even when the residues are fortified with nitrogen fertiliser. Direct effects of the large dressings of FYM produced the same yield of beet as did fertilisers, but they produced more carrots in the poorer growing season. Inorganic-N added with fresh FYM increased beet yields greatly, but not of carrots. Our present conclusions are that at Woburn soils given FYM regularly are better in poor seasons than soils given fertilisers for maintaining the growth of sensitive horticultural crops. Crops grown on soils with accumulated residues of organic manures are likely to suffer less in a cold wet spring, or when it is dry later in the season, but in good seasons there is no special benefit, provided both FYM-treated and fertilised soils contain similar amounts of soluble P and K. (Johnston)

Experiments with nitrogen fertilisers

Anhydrous ammonia. Ammonia (82% N) is used extensively in the United States (in 1963 it supplied 41% of the directly applied N). It is now being sold in the United Kingdom, so we compared it with "Nitro-Chalk" (21% N) for spring wheat at Rothamsted and at Woburn, and for grass at Rothamsted. Table 3 shows that both fertilisers gave similar wheat yields at the amounts required to produce maximum yield, but that ammonia was inferior at the smallest amount tested. The smaller yields obtained from anhydrous ammonia in the grass experiment illustrate the need to seal the slits made by the injection tines to prevent loss of the gas. Because of the many flints in the surface soil and of its texture, the injector did not penetrate to the required depth and the slits were not sealed. (Widdowson and Penny)

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TABLE 3

Results from one experiment on grass and two with spring wheat comparing anhydrous ammonia with "Nitro-Chalk" in 1966

	Grass at Rothamsted				
	lb N/acre applied				
	0	112	224	336	448
	Yield of dry grass (cwt/acre from 3 cuts)				
Anhydrous ammonia	27·2	35·8	45·6	46·0	49·0
"Nitro-Chalk"		58·1	74·4	81·7	86·6

	Spring wheat at Rothamsted and Woburn			
	lb N/acre applied			
	0	56	112	168
	Yield of grain (cwt/acre at 15% moisture content)			
Anhydrous ammonia	19·3	27·2	38·2	41·7
"Nitro-Chalk"		33·8	39·2	40·4

Urea in NPK fertilisers. Experimental fertilisers (with % N : % P : % K ratios of 2 : 0·44 : 0·83) containing four different proportions of urea to ammonium nitrate (expressed as a percentage of the total N in the mix, urea was 100, 66, 33 and 0) obtained in 1965 (*Rothamsted Report* for 1965, p. 52) were used again. Two experiments with barley (one on Lower Greensand, one on Clay-with-Flints) compared yields from each of the eight fertilisers combine-drilled to give 56 or 112 lb N/acre. The barley was sown in mid-March and little rain fell until April. Fertilisers containing urea delayed emergence and decreased plant number; the losses from drilling 112 lb N/acre as urea were large. Table 4 shows that drilling 56 lb N/acre as urea was not damaging enough to give yields smaller than given by ammonium nitrate, but that drilling 112 lb N/acre, either as urea or as two-thirds urea and one-third ammonium nitrate, greatly decreased yields. The check from drilling 112 lb N/acre as ammonium nitrate was temporary, and few plants died; it gave the largest yield.

TABLE 4

Results from two barley experiments in 1965 and two in 1966 comparing fertilisers containing varying amounts of urea to ammonium nitrate

(cwt/acre of grain containing 15% moisture)

		1965 experiments		1966 experiments	
Yield without fertiliser		19·4		28·6	
Composition of fertiliser		N applied (lb/acre)			
% urea	% ammonium nitrate	56	112	56	112
100	0	37·7	43·0	41·1	32·0
66	33	37·2	44·0	42·9	40·6
33	66	36·4	43·3	42·9	46·3
0	100	36·9	41·5	42·2	48·4

An experiment at Rothamsted compared yields of kale from the same eight fertilisers, broadcast to give 140 or 280 lb N/acre. Although urea at 280 lb N/acre killed some plants, each fertiliser produced similar yields. (Widdowson, Penny and Gasser)

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Urea nitrate and urea phosphate. The disadvantages of urea are that it damages germinating seeds and young plants and is less efficient than other nitrogen fertilisers when it decomposes rapidly so that ammonia is lost to the air. These can be diminished by mixing the urea thoroughly with the soil, by placing it to the side of seeds or by applying it with acid fertilisers such as superphosphate. An alternative is to make one of the addition compounds which urea forms with acids. Laboratory methods were developed to make urea nitrate ($CO(NH_2)_2{\cdot}HNO_3$, with 34% N) and urea phosphate ($CO(NH_2)_2{\cdot}H_3PO_4$ containing 17% N and nearly 20% P). Both are crystalline and easy to handle.

Urea nitrate was compared with ammonium sulphate for ryegrass grown in the glasshouse and with ammonium nitrate for permanent grass in the field. In the glasshouse large dressings of urea nitrate damaged early growth of ryegrass grown in Woburn sandy-loam, but not in Rothamsted clay-loam; on average urea nitrate produced less grass, containing less fertiliser nitrogen, than ammonium sulphate. Urea nitrate also damaged the permanent grass, which yielded less, and contained less nitrogen than with ammonium nitrate. Other field experiments at Rothamsted and Woburn compared urea nitrate and urea phosphate with ammonium nitrate applied to ryegrass and barley; at Woburn early growth of barley was least good with urea nitrate. On average urea nitrate and ammonium nitrate gave similar yields of barley grain and similar *total* yields of rye-grass, but yields from the early cut at Woburn were less with urea nitrate.

Urea phosphate did not damage plants, and at Woburn it and a mixture of urea with urea phosphate gave slightly larger yields of barley grain than a dressing of ammonium nitrate supplying as much nitrogen. At Rothamsted the three fertilisers gave similar yields of barley and of rye-grass. At Woburn yields at the first cutting of ryegrass were similar, but at the second cutting both urea phosphate and the mixture of urea phos-phate with urea gave significantly more. The grass took up significantly more nitrogen from the urea fertilisers (62 and 65%) than from ammonium nitrate (48%).

Both urea nitrate and urea phosphate are efficient sources of N for crops, but the same precautions are needed with the nitrate as with urea itself to prevent damage to crops. Combining urea with phosphoric acid made it safe and as efficient as equivalent N supplied as ammonium nitrate at Rothamsted and more efficient on the light soil at Woburn. (Gasser, Hamlyn and Penny)

Isobutylidene diurea for conifer seedlings. A slow-acting N fertiliser, isobutylidene diurea (IBDU) (made in Japan and described by Hamamoto (*Proc. Fertil. Soc.* No. 90, 1966)), was tested on Sitka spruce (*Picea sitchensis*) seedlings at Wareham Nursery in 1965. Two amounts of IBDU in 0·8–1·4-mm granules dug in in late March were compared with three topdressings of "Nitro-Chalk" applied in summer, supplying the same total N. Early in the season the plants with IBDU had excellent colour, but later they became slightly pale. However, the harvested seedlings were taller with IBDU than with "Nitro-Chalk":

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g N/sq yd	Height (in.)	
None	0·4	
	"Nitro-Chalk"	IBDU
9	1·4	1·6
18	1·6	2·1
S.E.	±0·17	

In 1966 two sizes of IBDU (0·8–1·4 and 1·5–2·4 mm) were compared at Wareham and Kennington Extension with formalised casein and "Nitro-Chalk". IBDU and formalised casein were applied before sowing, "Nitro-Chalk" was split into four topdressings given at the beginning of June, July, August and September. Four amounts of the materials were tested. Table 5 shows that the largest amount of N increased seedling

TABLE 5

Comparison of four nitrogen fertilisers for Sitka spruce seedlings in 1966

Small N = mean of 6 and 12 g N/sq yd
Large N = mean of 18 and 24 g N/sq yd

	Height (in.)			
	Wareham		Kennington Extension	
Without nitrogen	0·4		1·1	
	Small N	Large N	Small N	Large N
"Nitro-Chalk"	1·8	3·0	2·2	2·8
Formalised casein	1·6	2·7	2·3	2·9
IBDU (0·8–1·4 mm)	1·4	2·9	1·9	2·7
IBDU (1·5–2·4 mm)	2·0	2·8	2·0	2·6
S.E.	±0·11		±0·12	

height $2\frac{1}{2}$ times at Kennington Extension and 7 times at Wareham, with only small differences between forms of fertiliser. At Wareham (in autumn) the "Nitro-Chalk" plots were greenest, closely followed by coarse IBDU; plants with formalised casein and the fine IBDU were much paler. At Kennington Extension the differences were smaller—with "Nitro-Chalk" again best, followed by formalised casein and then by the two fractions of IBDU. The different nitrogen forms gave similar plant numbers in 1965 and 1966. Exceptionally heavy rain in July 1965, and in April and August 1966—especially at Wareham—may have favoured IBDU, which needs further testing to find its value in drier years. (Benzian)

Granulated oxamide for ryegrass. In the experiment on ryegrass described in *Rothamsted Report* for 1965 (p. 53) no more fertiliser-N was applied and the grass was cut in May and in June. Dry matter and N uptake were increased least (1·4 cwt/acre and 3 lb N/acre respectively) by 100 lb N/acre as ammonium nitrate applied in 1965, and most (12·7 cwt/acre and 25 lb N/acre) by the large granules of oxamide supplying 200 lb N/acre. In the total of five cuts taken in 1965 and 1966 the largest percentage of fertiliser-N was recovered from ammonium nitrate; similar and slightly smaller percentages were recovered from powdered oxamide, from small granules at 100 lb N/acre and from all three sizes of oxamide at 200 lb. Least fertiliser-N was recovered from the large granules of oxamide applied at 100 lb N/acre. (Gasser, Hamlyn and Penny)

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Comparisons of ammonium and nitrate for wheat, kale and ryegrass. Kloka spring wheat, thousand-headed kale and Italian ryegrass (S.22) were sown in a microplot field experiment testing no nitrogen and 50 and 100 lb N/acre applied as ammonium sulphate (treated with "N-Serve" (2-chloro-6(trichloromethyl)-pyridine) to prevent nitrification) and calcium nitrate. Crops were sampled nine times during the growing season. Up to 90 days after sowing 100 lb N as ammonium sulphate gave most dry matter and nitrogen uptakes with all crops; but thereafter kale and ryegrass grew better with nitrate and contained more N. Ryegrass contained most N when it was starting to flower 110 days after sowing; it contained a third more fertiliser N with ammonium sulphate than with nitrate, whereas kale contained a third more with nitrate. Nitrogen uptakes by kale from nitrate were greater because the crop was larger; it was greater by grass from ammonium sulphate because this increased the nitrogen content. (Spratt, Gasser, Hamlyn and Penny)

The effects of moisture stress on uptake of ammonium and nitrate by spring wheat. Four moisture régimes were compared in a microplot experiment with Kloka spring wheat at Rothamsted, using movable covers to prevent rain falling on the plots; 100 lb N/acre were applied as calcium nitrate or ammonium sulphate (treated with the nitrification inhibitor "N-Serve"). The crop was sampled on seven occasions. Without any moisture stress (irrigation used throughout the season to maintain the soil near to field capacity needed 9 in. of water), nitrate-N gave largest yields, as it also did when water was not given from germination to ear emergence, but the soil was kept at field capacity thereafter (6·5 in. of water were used). Ammonium-N gave larger yields than nitrate with unwatered crops or with those watered to maintain soil at field capacity only up to the flag-leaf stage. Without any moisture stress, 75% of the N supplied as calcium nitrate had been taken up by the crop at "dough" stage, but only 50% of the ammonium-N. With early irrigation only, moisture stress developed by the "dough" stage, when 48% of ammonium-N and 26% of nitrate-N had been taken up. (Spratt and Gasser)

Experiments with phosphate fertilisers

Residual and cumulative effects at Rothamsted. Two experiments were started in 1959 to compare the residues from superphosphate, three nitrophosphates, potassium metaphosphate, basic slag and Gafsa rock phosphate, and results of the first rotation (1960–62) were described in the *Rothamsted Report* for 1962 (p. 53). Table 6 summarises results in the second rotation (1963–65) and in both rotations.

In the second rotation the residues of all forms of phosphate applied once only (in 1959) significantly increased average potato yields by 0·9–1·7 tons/acre/year and average swede yields by 7·7–10·1 tons/acre/year. Increases in yields of barley from either residues (1·0–3·5 cwt/acre/year) or from annual dressings (1·1–3·3 cwt/acre/year) were small and irregular. Potatoes yielded slightly less with residues from Gafsa rock phosphate or

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TABLE 6

Effects of phosphate fertilisers over 3 and 6 years

	Rate (lb P/acre)	1963–65 Potatoes (tons)	1963–65 Barley (cwt)*	1963–65 Swedes (tons)	1960–65 Potatoes (tons)	1960–65 Barley (cwt)*	1960–65 Swedes (tons)
		Mean yields/acre					
Yield without P	0·0	10·6	35·8	7·9	10·5	34·4	7·8
		Increases in yield					
Annual dressings of superphosphate	12·3	1·4	3·3	9·3	1·1	2·7	8·7
	24·6	2·4	1·1	11·8	2·1	1·5	11·0
Single dressing of Gafsa rock phosphate	148	1·1	3·5	7·9	1·4	4·6	10·4
Basic slag	148	0·9	1·0	8·2	1·7	3·5	10·4
Nitrophosphates with 5 % of total P soluble in water	148	1·7	2·4	10·0	2·1	2·2	12·0
Nitrophosphates with 26 % of total P soluble in water	148	1·4	2·3	9·8	2·1	2·8	11·4
Nitrophosphates with 50 % of total P soluble in water	148	1·3	2·3	10·1	2·0	2·6	11·6
Potassium metaphosphate	148	1·4	2·5	7·7	2·0	3·8	10·4
Superphosphate	148	1·5	2·5	8·7	2·1	3·8	11·2
S.E. of increase		±0·31	±1·04	±0·79	±0·24	±0·79	±0·62

* Grain at 15% moisture.

basic slag than from superphosphate, three nitrophosphates or potassium metaphosphate; averaging the two rotations, potatoes yielded significantly less from rock phosphate residues. Residues from all the other forms of phosphate were similar for barley and swedes.

Annual dressings of superphosphate supplying 12·3 lb P/acre to the seed-bed gave yields in 1963–65 similar to those given by residues from phosphates applied in 1959, but superphosphate applied annually at 24·6 lb P/acre produced significantly more potatoes and swedes, and over the whole 6 years produced average yields similar to those from residues of all the P fertilisers except rock phosphate. The contrast is interesting, as the same total P (148 lb/acre) was used in the 6 years as was given in 1959. Hence, on this slightly acid soil, it made no difference whether the total phosphate is applied as one dressing or divided into six annual ones. (Mattingly)

Rates of action for agricultural crops at Rothamsted. Microplots were again used to measure rates of action and residual and cumulative values of three phosphates (*Rothamsted Report* for 1965, pp. 55–56), using Arran Pilot potatoes followed by radish. The fertilisers, which supplied 24 and 48 lb P/acre, were used as powders (<1 mm) and as granules 2–5 mm in 1965 and 1–4 mm in 1966); basal dressings of K and Mg (200 lb K and 50 lb Mg/acre) were adjusted to allow for these nutrients in the fertilisers; all plots received 100 lb N/acre at planting.

Table 7 shows that the immediate values (for potatoes) and residual values (for radish) of all the fertilisers were similar when applied as powders. Granules of potassium metaphosphate had less immediate value than the powdered fertiliser, and granulated magnesium ammonium phosphate acted very slowly. The residues from granules of potassium

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TABLE 7

Mean yields of early potatoes and radish in 1965 and 1966 from three phosphate fertilisers alone and together

(Results are means of yields from 24 and 48 lb P/acre to potatoes)

	Mean yields/acre (tons)			
	Potatoes		Radish	
	Powder	Granules	Powder	Granules
No phosphate	5·8		6·1	
Triple superphosphate (ts)	10·4	10·9	14·5	15·1
Potassium metaphosphate (KmP)	10·0	8·8	14·7	17·4
Magnesium ammonium phosphate (MgAmP)	9·7	6·7	15·3	15·5
ts + KmP + MgAmP	10·1	8·9	14·9	15·1
Standard error	±0·29		±0·47	

metaphosphate, but not from magnesium ammonium phosphate, gave significantly larger radish yields than the other fertilisers. (Mattingly, Penny and Blakemore)

Slow-release fertilisers for conifer seedlings. The experiment comparing potassium metaphosphate with potassic superphosphate (tested with and without topdressings of potassium nitrate) and with potassium dihydrogen phosphate was continued. Treatments and previous results were described in *Rothamsted Report* for 1964 (pp. 55–57) and for 1965 (pp. 56–57).

Rainfall in spring was more and leaching more than in 1965, but less than in 1964. Table 8 shows that the standard water-soluble PK com-

TABLE 8

The effect of P and K fertilisers on 1-year Sitka spruce seedlings at Wareham in 1966

	Rates applied (g element/ sq. yd)		Height	Dry matter of tops	Colour	P (%)	K (%)
	P	K	(in.)	(mg/ plant)	score*	(in dry matter)	
No fertiliser	0	0	0·5	34	6	0·17	0·28
Superphosphate only	9	0	0·4	38	6	0·26	0·24
PK compound (from super + KCl)	9	9	0·9	76	6	0·25	0·27
Potassium dihydrogen phosphate	9	12	1·5	114	5	0·22	0·33
PK compound + KNO_3	9	15	2·0	142	0	0·21	1·05
Potassium metaphosphate	9	12	2·3	159	2	0·23	0·52

* For the purple and yellow discoloration typical of K-deficiency (0 = no discoloration).

pound (made from superphosphate and potassium chloride), which had been no better than superphosphate after the exceptionally wet spring of 1964, trebled plant height in 1965, and doubled it in 1966. Supplementing the PK compound with potassium nitrate in 1966 doubled seedling height, showing the large gains possible from supplying K in mid-season. Seedlings produced by potassium metaphosphate were of excellent size, but, in

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contrast to 1964 and 1965, had no more than 0·5% K and were slightly discoloured, though not nearly as much as seedlings (containing less than 0·3% K) grown with potassic superphosphate. As previously, KNO_3 top-dressings maintained % K about 1·0.

The effects obtained with conifer seedlings are much larger than those obtained with agricultural crops. Averaging 3 years results, and with potassic superphosphate as standard, both potassium metaphosphate and potassium nitrate increased seedling height by half; potassium metaphosphate doubled percentage of potassium in the plants, and potassium nitrate trebled it. The concentration of P in the plants was little altered. (Benzian, Bolton and Mattingly)

Residual effects of NPK fertilisers

The experiments started in 1963 (*Rothamsted Report* for 1964, p. 60) to measure the residual effects on wheat of NPK fertilisers given to potatoes were continued; there were two in 1965 and in 1966, all on heavy land. The 1964 summer and autumn and 1965 winter were much drier than average, and so little nitrogen was leached from the soil. Consequently, after heavily manured potatoes, wheat also given a spring topdressing of N lodged in June. At Woburn (in 1965) lodging was so severe that the largest yield (42·9 cwt grain/acre) came from unmanured wheat grown after unmanured potatoes. The loss from applying 15 cwt/acre of "13: 13:20" compound fertiliser for the preceding potatoes, without further fertiliser to wheat, was 10·3 cwt grain/acre; from applying 10 cwt/acre to the wheat, but none to the potatoes, the loss was 18·6 cwt grain/acre (results from this experiment are omitted from Table 9). At Rothamsted yields were increased by the fertiliser applied for the potatoes when fertiliser was not applied to the wheat, but not when it was. Hence manuring the wheat gave no benefit in either experiment. Wheat yields were increased by fertiliser applied for both crops in the other five experiments, and the best amount to give the wheat depended on how much had been applied for potatoes and on the winter rainfall. Table 9 shows that the effect of the residues from the large dressing of compound fertiliser given to potatoes was equivalent to the direct effect on wheat of about one-quarter as much fertiliser of the same kind. (Widdowson and Penny)

TABLE 9

Mean yields from six experiments where wheat was grown after potatoes 1963–66

(cwt/acre of grain containing 15% moisture)

Fertiliser applied to wheat (equivalent to 13 : 13 : 20) (cwt/acre)	cwt/acre of 13 : 13 : 20* fertiliser applied for potatoes			
	0	5	10	15
0	27·2	31·0	34·1	39·1
5	41·0	41·8	44·3	43·2
10	44·7	44·4	46·1	46·0

* Compound fertiliser with 13% N, 13% P_2O_5, 20% K_2O.

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New manuring experiments on Park Grass

The history and results of the Park Grass Experiment were reviewed in *Rothamsted Report* for 1963 (pp. 240–262), and changes in treatments intended to make the experiment more useful were described in the 1964 Report (pp. 224–228). In 1965 microplots were sited within two of the plots outside the new liming scheme on Park Grass to test treatments relevant to modern grassland management.

Amounts and frequency of nitrogen manuring. Forty microplots were laid down on half of Plot 6, which had received PKNaMg fertilisers annually since 1869. The soil is rich in soluble P and K, but was acid, and was therefore limed. The original sward had about 40% grasses, 30% legumes and 30% of other species. The most N applied to Park Grass is 129 lb N/acre/year as ammonium sulphate, given as a single spring dressing. This is the smallest amount in the new test, which includes 258 and 387 lb N/acre (all as "Nitro-Chalk" to prevent the soil becoming acid again). Each amount of N was applied in either three or six equal dressings, one for each cut taken. In 1965 the plots were cut at regular intervals from mid-May to mid-October, the "three-cut" plots when the second, fourth and sixth cuts were made on the "six-cut" plots. In 1966 cutting was less regular; the "six-cut" plots were cut about once a month and the "three-cut" plots when necessary, but at the last harvest in October all plots were cut. Some plots not given nitrogen fertiliser were sprayed (twice in both years) with herbicide to kill legumes (weeds were also killed) and so get some estimate of their contribution to nitrogen supply in this mixed herbage.

Table 10 shows the sprayed plots yielded similarly in both years, but much less than unsprayed ones. The more frequent cutting lessened yield by about 8 cwt/acre of dry matter. Unsprayed plots without nitrogen

TABLE 10

The effect of rate of nitrogen fertiliser and frequency of cutting on the yield of permanent grass; Park Grass 1965–66

(Yields of dry matter for 2 years (cwt/acre))

Total N (lb/acre/year)	N applied and plots cut: 3 times		6 times	
	1965	1966	1965	1966
0 unsprayed*	59·6	68·3	40·1	46·1
0 sprayed*	36·4	34·1	26·1	27·0
129	84·8	84·1	62·1	67·4
258	107·7	109·4	79·9	92·2
387	111·8	105·1	93·1	107·3

* Spraying with herbicide to kill legumes.

fertiliser also yielded more when cut less frequently; the legumes present in the sward are mostly red clovers, which grow better when not cut too often. With both cutting régimes these plots yielded more in the second than in the first year, probably because chalking in 1965 increased the pH. Plots deriving N from legumes yielded less than plots given the smallest

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amount of fertiliser N in either year. On plots cut three times 258 lb N/acre sufficed for maximum yield in both years, but not on plots cut six times. With six cuts the largest yields with nitrogen fertiliser were more than double those without nitrogen, and a little less than double with three cuts. Three cuts gave larger yields of dry matter than six cuts, except with the largest amounts of N in 1966.

It is already evident that this old sward can give large yields provided enough nitrogen is given, and that getting largest yields of young herbage by frequent cutting needs more nitrogen than when cutting is less frequent. (This discussion takes no account of differences in quality of herbage; grass cut less frequently is less digestible, and so does not justify as much nitrogen.) The experiment has shown some of the difficulties in using nitrogen fertiliser on permanent grass that is cut and never grazed. The sward on plots given most nitrogen and cut least often has deteriorated rapidly; there is now much bare ground surrounding tussocks of cocksfoot and clumps of hogweed (*Heracleum sphondylium*). The same total amount of N applied in smaller amounts more frequently, and with the grass cut more often, has not damaged the sward as much.

Interactions of N, P and K. When large yields are taken from grassland it is difficult to decide how much phosphorus and potassium should be used to maintain fertility. Enough is needed to secure the maximum response to nitrogen and to prevent soil reserves being depleted, but too much is wasteful because the crop is likely to take up more than is needed to give maximum yield, and too much potassium carries some risk to animal health. Interactions between N, P and K fertilisers are being examined by testing four amounts each of P and K factorially at two rates of nitrogen. Two of the old plots of Park Grass were used, one very poor, the other rich in P and K. Originally both were plot 5, which had only ammonium sulphate from 1852 to 1897; since 1898 plot 5/1 has been unmanured and plot 5/2 has had P and K each year. Both plots were acid and were chalked in early spring 1965. Phosphate is now applied in late winter at 0, 15, 30, 60 lb P/acre/year and potassium at 0, 100, 200, 400 lb K/acre/year. Four cuts were taken in 1965 and three in 1966; the total amounts of nitrogen tested (divided into dressings given equally before each cut) were 133 and 267 lb/acre in 1965 and 150 and 300 lb/acre in 1966.

Because plot 5/2 has had PK for 65 years and 5/1 none, the species of plants in the swards on the two plots differed considerably. In 1949 on plot 5/1 82% of the herbage was grass (more than 90% *Festuca rubra* and *Agrostis vulgaris*). On plot 5/2 only 44% of the herbage was grass, 26% was legumes and 30% weed species; *Festuca rubra* and *Agrostis vulgaris* accounted for only 43% of the grasses, and *Alopecurus pratensis* was the other dominant grass (20%). The legumes were dominated by *Lathyrus pratensis* (65%) and the weed species by *Achillea millefolium* (43%).

Each treatment gave similar yields in both years. The results in Table 11 are averages for the P test over all amounts of K and for the K test over all amounts of P. Fresh P or K did not increase yield on the rich plot (5/2), and it will be interesting to see how quickly the reserves are depleted. On soil without residues (plot 5/1) phosphate increased yields, and

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TABLE 11

The effect of N, P and K fertilisers on yield of permanent grass grown with and without residues of PK fertilisers on Park Grass in 1965–66

(Mean yields of dry matter for 2 years (cwt/acre))

	Rate of nitrogen	New phosphorus, lb P/acre/year			
		0	15	30	60
Without PK residues (plot 5/1)	N1	38·8	55·2	59·4	66·6
	N2	37·9	63·6	75·1	79·9
With PK residues (plot 5/2)	N1	77·6	70·4	76·3	71·6
	N2	93·2	94·8	95·4	98·4
		New potassium, lb K/acre/year			
		0	100	200	400
Without PK residues (plot 5/1)	N1	49·7	57·4	56·8	56·1
	N2	57·0	66·4	68·2	64·8
With PK residues (plot 5/2)	N1	74·4	77·6	73·2	70·8
	N2	95·0	93·2	96·6	97·0

the largest dressing was needed for maximum yield. There was a response to fresh potassium on plot 5/1, but 100 K/acre sufficed for maximum yield. The extra response to the double dose of nitrogen was always smaller on plot 5/1 than on plot 5/2; the fescue-dominated herbage on plot 5/1 (no PK residues) yielded no more with the extra N unless phosphate was given. (Whether the *same* species grown alone on soil with and without P residues would behave like this is not known.) All combinations of nutrients applied to the rich plot 5/2 gave a larger yield than on the depleted plot 5/1, possibly because of differences in the responses of the different species present in the two swards. Applying P and K has not changed the botanical composition of the herbage on plot 5/1. (Johnston and Penny)

Potassium, sodium and magnesium fertilisers for kale

The long-term experiment at Woburn testing potassium and magnesium fertilisers was modified to test effects on kale of sodium chloride supplying 130 lb Na/acre. (All plots had 2 cwt N/acre.) Sodium significantly increased yield of kale, especially without giving potassium:

lb K/acre applied	Yield of kale dry matter (tons/acre)	
	Without sodium	With sodium
0	3·4	5·0
140	5·9	6·4
280	5·7	6·4

Standard error $\pm 0{\cdot}25$

Analyses in June showed that most of the sodium (applied half in winter and half in spring) remained in the 0–9-in. layer of soil, in spite of much rain in winter and spring, whereas most of the chloride had gone, removed either by leaching or by the crop.

The large response to potassium occurred whether or not magnesium was given. Although plants on some plots showed signs of magnesium deficiency during the summer, responses to Mg were small. The largest

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dressing (88 lb Mg/acre) increased average yield of kale from 5·3 to 5·7 tons dry matter/acre. (Bolton and Penny)

Effects of fertilisers on crop composition

The effect of a nitrification inhibitor ("N-Serve") on the concentration of nitrate in plants and on fertiliser efficiencies. The nitrate was measured in winter wheat collected 32 days after applying the fertilisers and in grass collected 68 days after fertilising, from field experiments described in the *Rothamsted Report* for 1964 (pp. 53–54).

Winter wheat accumulated nitrate from large dressings of untreated ammonium sulphate, more from the clay-loam soil at Rothamsted than from sandy loam at Woburn. Treating the ammonium sulphate with the inhibitor greatly diminished the nitrate in plants at Rothamsted but not at Woburn, possibly because the inhibitor was lost faster from the lighter Woburn soil.

Grass given 100 lb N/acre did not contain significantly more nitrate-N than unfertilised grass, but grass with 200 lb N/acre did; increases were less with the inhibitor than without. Increasing the amount of inhibitor made it more effective. (Nowakowski and Gasser)

TABLE 12

The effect of a nitrification inhibitor on the concentration of nitrate in grass at various stages of growth

		Yields, totals of 3 cuts		Amounts of nitrate-N (ppm) in grass dry matter						
Nitrogen applied* (lb/acre)	Inhibitor	Dry matter (cwt/acre)	N in crop (lb/acre)	17 May	31 May	14 June	28 June	14 July	28 July	15 August
None	—	39	78	270	110	50	100	250	170	160
100	without	89	252	2,760	1,080	690	420	2,800	1,120	860
100	with	92	248	1,450	1,080	500	180	890	600	260
200	without	111	438	5,170	6,970	6,820	4,380	6,700	5,440	4,530
200	with	121	493	1,750	2,610	1,630	1,790	1,850	1,670	1,650
L.S.D. (P = 0·05)		13·7	70	—	—	—	—	—	—	—

* Ammonium sulphate was applied on 30 March and on 28 June. Grass was sown on 30 March, emerged on April 21, was cut on 28 June, again on 15 August and a third (residual) cut was taken on 20 October.

An experiment at Rothamsted examined the effect of the nitrification inhibitor on the accumulation of nitrate in Italian ryegrass and on the efficiency of the ammonium sulphate applied. The grass was analysed every 2 weeks. Table 12 shows that grass given ammonium sulphate with the inhibitor contained much less nitrate-N than grass given ammonium sulphate alone, especially with the larger dressing. Three months after fertilising, grass given the larger dressing of untreated ammonium sulphate had two and a half times more nitrate than grass given treated ammonium sulphate. Yields, and the percentages of N recovered by the grass, were not significantly increased by the inhibitor, but it seems that using a nitrification inhibitor may allow more ammonium fertiliser to be applied without risking a dangerous increase in the nitrate content of grass. (Nowakowski and Penny)

Accumulation of nitrate in wheat affected by "scorch". The condition in cereals we call "scorch", which is associated with light soils, large dressings

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of nitrogen and drier than average weather, was described by D. B. Slope (*Rothamsted Report* for 1963). Whether the primary cause is soil-borne pathogens (Slope showed *Fusarium* spp. commonly invaded roots of affected plants), or whether drought and too much N fertiliser weaken resistance of roots to infection, is unknown. Spring wheat on the irrigation experiment at Woburn in 1966 was sampled through the season to determine whether the appearance of scorch was correlated with changes in the chemical composition of plants. The experiment (described on p. 268) tested on wheat four amounts of nitrogen ranging from 45 to 180 lb N/acre, irrigation *v*. none (up to 9 June 2 in. water were applied to maintain the soil-moisture tension at 1 in. or less) and the effects of a "dwarfing compound" CCC (2-chloroethyltrimethyl-ammonium chloride), which shortens internodes and may encourage tillering.

Scorch symptoms showed in early June after "dry weather" from 9 May to 8 June (0·88 in. rain fell from 9 to 25 May, no measurable rain from 26 May to 6 June and 0·03 in. on 7 June), when much of the leaf area of unirrigated crops given the most fertiliser-N was affected. Eye estimates of the proportion of leaf area "scorched" on 8 June showed that without irrigation scorch increased with increasing amounts of fertiliser-N; with irrigation there was little scorch, and its incidence differed little with difference in fertiliser-N.

The mineral-N (ammonium + nitrate) content, almost entirely nitrate, was determined in whole plants. With the smaller amounts of fertiliser all plants contained less than 100 ppm mineral-N. With the two larger amounts they contained more, but how much depended on whether they were irrigated and/or sprayed with CCC, because spraying decreased the mineral-N in unirrigated wheat and increased it in irrigated wheat. Mean values for crops given 135 and 180 lb N/acre were:

	Mineral-N (ppm in dry matter)	
	No irrigation	Irrigation*
No spray	840	140
CCC spray	350	340

* To maintain soil moisture tension at 1 in. or less.

The crop was sprayed with CCC on 16 May, and sampled on 1, 8 and 14 June (the last immediately before heading). The percentage dry matter in the crop was greatly affected by treatment; irrigation and increasing N both decreased dry-matter percentage of samples taken on 14 June. CCC spray decreased dry matter in the unirrigated crop and increased it on the irrigated. Unsprayed irrigated wheat had 16% dry matter and unsprayed unirrigated wheat 29%. CCC did not affect scorch.

The fact that the wheat with most scorch contained six times as much nitrate as wheat with least scorch does not prove that nitrate accumulation causes scorch, and other analyses are being made to see whether there are other unusual features in nutrient uptake. (Gasser and Thorburn)

The effect of source of potassium on protein synthesis by grass. Udovenko and Min'ko (*Fiziologiya Rast*. (1966), **13**, 236–45) showed that potassium chloride and sulphate differ in their effect on the synthesis of protein and other nitrogenous compounds in detached leaves. An experiment with

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Italian ryegrass in pots compared KCl and K_2SO_4 supplying 125 and 250 ppm of K. The two forms similarly increased dry-matter yields, N-uptake and percentage of true protein. The only striking difference was the smaller amounts of asparagine and glutamine, expressed as a percentage of total N in plants given the large dressing of sulphate (Table 13). Effects

TABLE 13

Effect of form of potassium fertiliser on the composition of the nitrogen-containing fraction of ryegrass

	K applied (ppm)	Expressed as % of total N				
		True protein-N	α-amino-N	Total amide-N	Glut-amine-N	Aspar-agine-N
Without K	—	68	6·6	3·6	1·9	1·6
KCl	125	75	6·1	3·2	1·4	1·9
K_2SO_4	125	77	6·3	2·7	1·3	1·3
KCl	250	78	5·3	2·7	1·3	1·4
K_2SO_4	250	78	4·7	1·8	1·0	0·8

of this kind may be important. For example, of the nitrogen in the grass given the larger dressing, 2·7% was in the amide fraction of plants given potassium chloride and 1·8% in those given potassium sulphate. As amide readily breaks down in the rumen to ammonia, this difference could affect animal nutrition. (Nowakowski)

The effect of potassium on growth and protein content of ryegrass. In a glasshouse experiment with ryegrass grown on a sandy loam soil with only 55 ppm of exchangeable K yield responses to potassium fertiliser increased with increases in the amount of nitrogen applied (as ammonium nitrate), and the largest amount of K applied (as potassium chloride) was needed only with the most N. A surprising effect was that when potassium was not given, nitrogen greatly diminished root weights; with each amount of N used, root weights increased with increases in the K given (Table 14).

TABLE 14

Effects of nitrogen and potassium fertilisers on yields of tops and roots of ryegrass

K applied* (ppm)	Dry matter in tops (g/pot) (total of 2 cuts)			Dry matter in roots (g/pot)		
N applied* (ppm)	56	167	334	56	167	334
0	10·0	15·8	9·0	10·0	7·1	2·0
125	12·5	21·1	18·8	13·8	13·6	4·3
250	12·4	23·1	21·2	16·0	15·1	6·6
500	11·9	23·1	24·4	12·8	16·8	8·3

* Amounts of K and N applied are expressed as parts per million of weight of soil used.

With most N and no K, regrowth after the first cut was very small, probably because of the very small root system. Such effects may be important where much nitrogen fertiliser is used on grass.

Crop analyses showed that potassium had little effect on protein synthesis with the small amount of N, but considerably increased the true protein content produced with much N. (Nowakowski)

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Changes in soil nitrogen caused by green manuring

The soils of the experiment at Woburn on green manuring (*Rothamsted Report* for 1962, pp. 193–197), which is ending, were sampled 8 in. deep in January to measure changes in soil nitrogen and carbon caused by green manuring and by organic manures applied since 1936. Dates of the last applications of organic manures and the green manures grown since 1954 are given (Table 15).

TABLE 15

Effects of green manures, FYM and straw on the total carbon and nitrogen of the soil (averaging all other treatments)

	Carbon		Nitrogen	
	Mean effect	% increase	Mean effect	% increase
Trefoil every year	0·12	15	0·011	13
Trefoil in alternate years	0·08	10	0·007	8
Ryegrass every year	0·08	10	0·006	7
Ryegrass in alternate years	0·06	7	0·005	6
FYM from 1936 to 1953	0·07	8	0·006	6
Straw from 1936 to 1964	0·06	7	0·004	4
Straw + FYM	0·13	16	0·009	10

Of the green manures, trefoil every year increased total carbon and nitrogen most; ryegrass every year had the same effect as trefoil in alternate years, and growing ryegrass in alternate years had the least effect. FYM at 10 tons/acre applied only from 1936 to 1953 had a larger effect than 30 cwt/acre of straw applied from 1936 to 1964 (both materials were applied in alternate years). The effect of FYM and straw applied together was roughly the sum of their separate effects.

Thirty years of continuous cropping without adding organic matter lessened the total carbon and nitrogen of the soil from 0·86% and 0·091% respectively in 1936 to 0·76% and 0·082% in 1966. Ploughing in straw alone approximately halved the loss, with the contents now 0·80% C and 0·085% N. FYM and green manures have both maintained the original percentages of soil carbon and nitrogen. The soil now richest (0·96% C and 0·099% N) had both FYM and straw and a green manure was grown.

Amounts of plant residues and their nitrogen contents. Large core samples were taken from the ploughed layer of some plots and "tops" (of green manures), and roots were extracted, weighed and analysed. The "fallow" plots contained residues of cereal roots, but no "tops". The amount of root material (and its nitrogen content) differed little between fallow plots and plots where ryegrass was grown each year; N-fertiliser given to the cereals increased the residues, and their nitrogen contents, on plots with and without ryegrass. On the ryegrass plots "tops" contributed more plant material, containing half as much nitrogen as the roots. On plots with trefoil and barley given no N-fertiliser the roots contributed no more organic matter than on fallow plots, but they were much richer in nitrogen; the tops and roots together contained about twice as much nitrogen as the ryegrass residues.

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Nitrogen given to the barley affected the establishment and growth of trefoil; after harvesting barley given 101 lb N/acre there were many patches devoid of trefoil and containing only weeds. On such plots the plant residues where trefoil was dense contained about twice as much nitrogen as where there was no trefoil (Table 16).

TABLE 16

The effects of green manuring and of nitrogen fertiliser on the weights of plant residues returned to soil, on their nitrogen contents and on mineralisable soil nitrogen

Green manure		N applied to barley (lb/acre)	Dry weight of plant residues (cwt/acre): Roots	Tops	Nitrogen in plant residues (lb/acre): Roots	Tops	Inorganic-N in sample cores (ppm): Before incubation	After incubation	Mineralisable N
None		34	40·5	—	68	—	6·2	8·6	2·4
		134	51·0	—	85	—	5·7	9·6	3·9
Ryegrass		0	51·4	17·3	62	32	5·8	2·3	−3·5
		101	57·0	18·0	80	41	4·8	5·7	0·9
Trefoil	Dense	0	40·5	26·8	101	112	9·2	20·2	11·0
	Dense	101	56·5	20·6	124	86	7·7	17·2	9·5
	Absent	101	53·1	6·9	90	19	5·4	12·6	7·2

Mineralisable nitrogen. Parts of the soil cores from which plant residues had been extracted were extracted immediately with *N*-potassium sulphate solution, and others after incubation, to measure the immediately available ammonium-N and nitrate-N and the amounts mineralisable. (The soil contained little extractable ammonium-N.) Table 16 shows that the fallow plots had a very little mineralisable nitrogen, and where ryegrass had been grown without nitrogen mineralisable-N was negative, indicating that N is being released more slowly than it was being used to decompose the ryegrass. Where much N had been given to barley on the ryegrass plots mineralisable nitrogen was zero, suggesting nitrogen released equalled nitrogen used in decomposing the residues. Trefoil plots without N-fertiliser contained about 10 ppm of inorganic nitrogen when sampled, and 20 ppm after incubation. Mineralisable nitrogen was less on trefoil plots given the large amount of N fertiliser, particularly where the legume grew poorly.

Other samples from the ryegrass and trefoil plots were incubated with dried and ground tops of the green manures, and with ground straw. Adding more dried ryegrass, with or without ground straw, before incubating soil from ryegrass plots given nitrogen did not affect mineralisable nitrogen. With soil from ryegrass plots not given nitrogen fertiliser, adding ryegrass tops slightly increased the available nitrogen (although mineralisable-N was still negative), but not when straw was also added. Extra trefoil added to soil from the trefoil plots increased mineralisable nitrogen, but not when straw was also added. (Chater and Gasser)

Changes in soil phosphorus potentials

Preliminary work on the changes in the potential of monocalcium phosphate ($0{\cdot}5pCa + pH_2PO_4$) caused by cropping the Rothamsted and Woburn

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soils was described in *Rothamsted Report* for 1964 (p. 67). This year 20 contrasted soils were examined in experiments with grass grown in pots. As previously, phosphate potentials (I) decreased linearly with the amounts (Q) of P removed by the grass. Over 70% of the variance in values of I was accounted for by linear regression on Q for 16 soils and over 90% for 11 soils. The gradient $\Delta I/\Delta Q$ differed more than 20-fold between the different soils. Table 17 gives initial values of the monocalcium phosphate potential (I_0) and its mean rate of changes ($\Delta I/\Delta Q$) during cropping of 10 soils representing 7 soil series. Changes on soils from Almonsbury and Castle Cary were small and difficult to measure. The buffering capacities of the soils varied inversely with $\Delta I/\Delta Q$. Saxmundham soil had a smaller buffering capacity than Rothamsted soils; Castle Cary soil had a much larger capacity than the soil from Moreton-in-Marsh, although both are in Sherborne Series. Table 17 emphasises that buffer capacities of individual soils can differ considerably within one series; $\Delta I/\Delta Q$ usually decreases as phosphate status increases.

TABLE 17

Initial values of monocalcium phosphate potentials (I_0) and mean rate of change ($\Delta I/\Delta Q$) during cropping in glasshouse pot experiments

Site	Soil Series	I_0	$\Delta I/\Delta Q$*
Kirk Smeaton, Yorks	Aberford	6·97	167 ± 22
Saxmundham, Suffolk	Ashley/Hanslope	8·41	119 ± 38
Woburn, Beds	Cottenham	5·65	95 ± 13
Alvediston, Wilts	Icknield	7·36	70 ± 22
Woburn, Beds	Cottenham (limed soil)	6·51	61 ± 7
Moreton-in-Marsh, Glos	Sherborne	7·96	58 ± 11
Hoosfield, Rothamsted	Batcombe	6·32	49 ± 5
Barnfield, Rothamsted	Batcombe	7·86	38 ± 7
Almonsbury, Glos	Evesham	8·53	16 ± 19
Castle Cary, Som	Sherborne	7·75	7 ± 10

* These values, $\times 10^{-4}$, represent mean changes in the numerical value of $\frac{1}{2}$pCa + pH$_2$PO$_4$ as 1 ppm P is removed by cropping.

An attempt was made to relate values of $\Delta I/\Delta Q$ to soil properties using multiple regression analyses. Variations in organic carbon content (0·72–5·45%) and total P content (342–4,260 ppm) for these (mostly arable) soils had no effect. Clay content was the most important variable and, for the 20 soils, regression on % clay ($<2\ \mu$), % $CaCO_3$ and 0·5*M*-$NaHCO_3$–soluble P together accounted for 70% of the variance in $\Delta I/\Delta Q$. After excluding seven soils, which solubility measurements suggested contained octacalcium phosphate, the regression accounted for over 80% of the variance. (Webber and Mattingly)

Cations in soils

Soil structure and potassium uptake. We are trying to relate the potassium-supplying power of soils to their series classification by exhaustively cropping them in pots. Because potassium diffuses only slowly in soil, uptake depends much on soil structure; structure affects the contribution that subsoils may make to potassium supply and makes it difficult to relate results in pots to those in the field. Comparisons were made of potassium and sodium uptakes by ryegrass grown in subsoil after drying

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and grinding, and in undisturbed cores of the same subsoils. Four soil series were used, taken all from one field which had been cropped and cultivated uniformly. Quantitative comparisons are not possible because the cropped area of pots and cores is about the same, but the cores contain more soil. Structure clearly affected both potassium uptake and the ratios of sodium to potassium in the grass. Uptakes of K and Na (as ppm of soil) were:

	K		Na	
Soil Series	In pots	Soil cores	In pots	Soil cores
Icknield	90	58	8	4
Coombe	95	47	11	7
Charity	88	34	14	12
Winchester	231	25	20	12

From Icknield subsoil, which is very chalky and friable, grass extracted two-thirds as much K from soil cores as from soil in the pots. By contrast, from Winchester series, which has a very tenacious and compact subsoil, grass extracted only a tenth as much K from the undisturbed cores as from the soil in pots. Sodium ions are much more mobile than potassium, and results with sodium differed strikingly. From both the soil series, grass extracted about half as much Na from cores as from soil in pots, the compact Winchester soil not interfering with sodium uptake at all.

Grass extracted similar amounts of K from topsoils and from ground subsoils. There were large differences between soils of different series, from 256 ppm removed from Winchester series to only 103 ppm removed from Charity soil. These differences may be connected with the proportion of clay in the soil and the potassium content of the clay, which on the soils used, differ by a factor of three:

	Top soil	Subsoil
Soil Series	% K in $<2\ \mu$ clay	
Icknield	0·48	0·32
Coombe	0·83	0·90
Charity	1·50	1·44
Winchester	1·30	1·05

(J. K. Coulter)

Release of cations in exhaustive cropping. The amounts of cations removed from six British soils and four from Malaya by S.23 ryegrass grown in pots were measured. After 9 months the plants were removed from the pots, the roots separated and the soils analysed. Balance sheets were calculated for potassium, sodium, calcium and magnesium.

Much non-exchangeable potassium was recovered from all the soils, except three tropical latosols that had very little in their clay. Potassium recovered in the grass, plus exchangeable potassium in the air-dried soils after cropping, averaged 2·8 times more than the initial exchangeable potassium with pots containing only 100 g of soil and 2·4 times more with pots containing 400 g. This was because plants in small pots produced more dry matter/unit weight of soil, but percentage potassium in successive crops in the two experiments was the same. Pot size and shape influence the amount of potassium removed from soils in experiments of this kind, probably because they affect rooting intensities.

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Some non-exchangeable sodium was recovered from soils with clay rich in sodium, but total sodium recovery and the initial exchangeable sodium in the soils were well correlated. (The small pots used were of polystyrene, each contained 1·28 mg of sodium, and the grass recovered about 90% of this!)

Calcium and magnesium recovered in the crops, plus the amounts left in the soils, correlated well with the amounts initially exchangeable. Non-exchangeable magnesium was not released, even though the last grass grown on some soils showed signs of magnesium deficiency.

The potassium contents of the first crop were linearly related to $\log_{10}$ (exchangeable potassium) in the soils ($r = 0{\cdot}98$ and $0{\cdot}96$ in small and large pots) but less closely related to potassium "intensity" $\left(-\log_{10}\frac{a_K}{\sqrt{a_{Ca+Mg}}}\right)$ measured in 0·01M-calcium chloride solutions in equilibrium with the soils.

The sodium contents of the first crop were related to the exchangeable K : Na ratio in the soils ($r = 0{\cdot}82$), but this ratio was even more closely related to Na : K ratio in the grass ($r = 0{\cdot}97$). (Bolton)

Effects of formalin and nitrogen on the yields of spring wheat

The experiments started in 1965 (*Rothamsted Report* for 1965, p. 49) on Little Knott (a field mainly used to grow cereals for 20 years) and Pastures (ploughed from 10-year-old grass in February 1964) were continued. Formalin freshly applied for the 1966 crops was tested in all combinations with the formalin applied in 1965. The plots on Little Knott treated with formalin in 1965 yielded less than untreated plots (repeating the results on Butt Close at Woburn in 1965), but plots treated in 1966 yielded much more than untreated plots; the effect of treatment in 1965 was negligible on plots also treated in 1966. On Pastures field formalin applied in 1965 increased yields on plots not given nitrogen, but had little effect on those where it was given. Formalin applied in 1966 greatly increased grain and straw yields where nitrogen was not given (whether or not formalin was applied in 1965), and it increased yields of straw, though not of grain, where nitrogen was given (Table 18). Although yields ranged more on

TABLE 18

The effects of applying formalin and nitrogen for spring wheat at Rothamsted in 1966

(cwt grain/acre at 15% moisture content)

N applied (lb/acre)	Little Knott field Formalin Without	With	Pastures field Formalin Without	With
0	16·2	28·4	28·4	36·9
56	24·5	37·3	39·2	39·5
112	32·2	40·3	39·2	39·0
168	33·7	39·7	36·0	33·4

Little Knott than on Pastures, the largest yields of grain (but not of straw) were the same on both fields. So, as in 1965, the benefits to spring wheat

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from the long ley on Pastures were matched by the benefits from formalin on Little Knott, provided that the correct dressing of nitrogen was given. (Widdowson and Penny)

Residues of simazine in soils

The herbicide simazine (2-chloro-4,6-bisethylamino-1,3,5-triazine) persists in soil, and where more than recommended dressings have been given residues may be enough to damage following crops. Accidental overdoses of simazine in 1961 produced sterile patches on our farm, which were described in the *Rothamsted Report* for 1963 (p. 70). Further work on one of these patches still toxic to crops is described in the report of the Field Experiment Section (p. 234).

Published accounts of work on simazine residues in soil gave no complete account of the ways in which the herbicide is retained in soil, of the effects of other substances on its solubility or of the effect of soil type on the persistence, solubility and movement of simazine. To gain further information on these points, work was started on adsorption of simazine from 0·01*M*-calcium chloride solutions in equilibrium with soil, and on desorption by two extractions with simazine-free calcium chloride solution. The adsorption reaction seems not to be completely reversible, for only about 90% of the theoretically predicted amount was desorbed. This may indicate that a secondary reaction occurs between simazine and soil, distinguished from the initial adsorption; if it does, it will complicate kinetic studies of the way simazine disappears from soil.

Samples taken at 3-ft intervals across the patch on Great Knott III Field contained 0·03, 0·12, 2·7, 10, 1·0 and 0·09 ppm of simazine, showing that the original overdose was on a very small area and that the herbicide had not been dispersed much by later cultivations. At the centre of the patch, where the surface soil had 10 ppm of simazine, samples of the subsoil 9–18 in. and 18–27 in. deep contain only 0·2 ppm, suggesting that, if simazine is leached into the subsoil, it is quickly lost, either by being leached deeper or by decomposition. (J. D. H. Williams)

Apparatus and experimental methods

Simazine in soils. The method of Delley and Stammbach (Analytical procedure No. 1034, 3 March 1964; J. R. Geigy, S.A., Basle, Switzerland) for determining total simazine in soils gave reproducible results and detected 0·02 ppm or less. Soil is extracted with redistilled ether and filtered; optical density measurements are made at three wavelengths (225, 240 and 255 mμ) to compensate for background adsorption. The extracts did not have to be cleaned, even though some of the soils contained much organic matter. (J. D. H. Williams)

Determining chloride in soils. A method for determining chloride (Iwasaki *et al.*, *J. chem. Soc. Japan* (1952), **73**, 835) based on measuring the red colour formed in the reaction

$$2Cl^- + Hg(CNS)_2 \longrightarrow HgCl_2 + 2CNS^- (+ Fe^{3+})$$

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was used for extracts of 5–10 g of soil in 0·01M-calcium nitrate solutions. It is more sensitive than titrimetric methods using silver or mercuric reagents, and needs no special apparatus. Ten non-saline soils (10-g samples ground to <80 mesh) had a mean chloride content of 12·9 ppm (standard error of 0·85 ppm for a single determination). Results varied more with unground soils, from which 95–105% of added chloride were recovered. The method can be used to measure chloride in rainwater. (Bolton)

Flame spectrophotometric analysis. A monochromator heater (Voss, *Spectrovision* (1966), No. 15, pp. 8–9) fitted to the SP.900A spectrophotometer shortens the time needed to reach operating temperature and allows measurements to be made for 1 hour more each day.

Interference by other ions in determining calcium depends much on the position of the burner head relative to the entrance slit (i.e. which part of the flame is used to measure emission). At the optimum position, where the emission of a pure calcium solution is maximal, other ions interfere most. Lowering the burner head relative to the entrance slit lessens the sensitivity for calcium alone, but lessens interferences by other ions much more, and can eliminate all interferences except those caused by silicon and aluminium. (Salt)

Our old medium quartz spectrograph was converted to direct reading of the lines. The original Lundegaardh burner/atomiser is still used, but a modified assembly based on EEL components is being made. (Smith)

Technicon AutoAnalyzer for phosphorus. The AutoAnalyzer is satisfactory for plant ash extracts, sodium carbonate fusions of soils and 0·5M-sodium bicarbonate extracts of soil. 60 samples of plant ash extracts and 30 samples of soil extracts are analysed per hour. (Salt)

Nitrogen in crops. The "Coleman Nitrogen Analyser" has now been used for several thousand samples of plant materials. Results with kale and grain were irregular because of variability in the small (100 mg) sample used for analysis. Although finer grinding and more careful sub-sampling may overcome this, we retain the Kjeldahl method (1 g sample) for these materials. (Hamlyn)

Losses of ammonia in handling plant material. More was done with the laboratory apparatus developed to measure losses of ammonia from decomposing plant material (Salt, *Chemy Ind.* (1965), 461–462). Tests on fresh samples of clover gave results similar to those with samples stored at $-15°$ C, ammonia started to be lost within 7 days when moist air was passed over stored samples, but not until 10 days for fresh samples. Loss of ammonia stopped after about 50 days and accounted for 30–45% of the total nitrogen. With dry air the stored samples decomposed faster than the fresh ones, but both lost less ammonia than with moist air because the samples dried.

Loss of nitrogen from decomposing clover depended not only on the

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moistness but on the flow of the air. When a sample dried without decomposing, ammonia was not lost, even when the material later decomposed in moist air. However, when only slight decomposition occurred during drying the loss of ammonia during later decomposition in moist air was independent of the amount of air passing over. (Salt)

Watering techniques in glasshouse experiments. Ryegrass, our commonest experimental crop for work with nutrients in soils and fertilisers, usually receives water in the saucers in which the pots stand. But during winter and early spring, when evaporation and transpiration are small, the soil tends to become anaerobic. In comparisons of six methods of watering from February to May, largest yields were by watering pots daily and maintaining the soil (by weighing) at 100% or 80% of the water-holding capacity. Yields were significantly less when pots were maintained at 60% of the water-holding capacity, or were watered on the surface (without weighing) and the soil allowed either to dry or to remain moist between waterings. Yields were also smaller from pots watered in their saucers. Table 19

TABLE 19

Yields of ryegrass (g dry matter/pot) in three cuts from six watering treatments

Treatment	Soil used: Sawyers	Great Field	Mean
Watered by weighing:			
100 % of water-holding capacity	22·6	25·8	24·2
80 % of water-holding capacity	21·7	27·4	24·5
60 % of water-holding capacity	16·2	24·6	20·4
Watered without weighing:			
Soil drying between watering	19·5	21·4	20·4
Soil surface kept moist	16·1	17·9	17·0
Watered in saucers	17·3	20·2	18·8
Standard error	±1·08		±0·76

shows striking differences in mean yields of grass from three successive cuts on soils from Sawyers (old arable) and Great Field IV (ploughed from grass in 1958). Results of pot experiments may be complicated by variations in watering technique and also by water × soil interactions; having the soil too dry had larger effects on yields from Sawyers arable soil than from the soil of Great Field, which was richer in organic matter. (Mitchell)

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