Report for 1964

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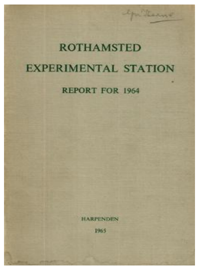

Chemistry Department

G. W. Cooke

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CHEMISTRY DEPARTMENT

G. W. COOKE

J. M. d'Arifat left to join the Commonwealth Bureau of Soils, and J. Bolton was appointed. R. K. Cunningham was seconded for three years as Professor of Soil Science in the University of the West Indies.

J. K. Coulter and T. Z. Nowakowski attended the 8th International Congress of Soil Science at Bucharest. F. V. Widdowson was an invited delegate to a Conference on Mechanisation of Field Experiments held under the auspices of NATO at Vollebekk in Norway. At the invitation of the International Potash Institute, G. W. Cooke and T. Z. Nowakowski attended a Symposium in Switzerland on the effects of fertilisers on the quality of crops. G. W. Cooke visited the International Atomic Energy Agency in Vienna.

D. F. Williams obtained the B.Sc. degree of London University, J. Bolton the M.Sc. degree of Leeds University and P. B. Hoyt the Ph.D. degree of London University.

The following visitors joined the Department: Mr. B. S. Coulter (Ireland), Mr. S. K. Dey (India) and Dr. D. J. Greenland (Australia).

Purpose of the Research Programme

The Department's work is concerned with chemical aspects of soil fertility (i.e., productivity). Traditionally, fertile soils are associated with ample organic matter and with using organic manures. Changes in amounts of soil organic matter caused by differences in cropping and manuring are therefore followed in long-term experiments at Rothamsted and Woburn; the ways organic manures increase crop yields are studied in both field and laboratory experiments. Fertilisers are tested in field experiments to find how amount and method of application, and chemical form, alter their effects on crop yields.

Besides increasing fertility immediately, and so raising crop yields, fertilisers alter the compositions of crops and soils. Both the amounts of inorganic ions taken up by crops and the proportions of the organic constituents elaborated by the plants may be altered. As both kinds of change affect the "quality" of crops (this is simply their suitability for a named purpose), the effects of fertilisers on organic and inorganic constituents are studied. Some fertilisers alter soils by increasing the leaching of nutrients, but in studying residues we are mostly concerned with benefits from nutrients left in soil, because these are most important now that farmers apply large fertiliser dressings to arable crops. Nitrogen fertilisers can have large residual effects, but these rarely last for more than one or two seasons. Phosphorus and potassium fertilisers are not readily leached from agricultural soils, and after long periods of manuring their residues change soil fertility greatly; they often lessen the need for fresh fertiliser, but they also raise fertility permanently so that larger yields are obtained

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irrespective of how much fresh fertiliser is used. In a large programme of laboratory, glasshouse and field work we study fertiliser residues, using mainly soils and crops from the long-term experiments at Rothamsted, Woburn and Saxmundham.

Often simple chemical measurements on soils are not well related to crop yields and responses to fertilisers because the amounts of nutrients roots take up depend on soil structure and other physical properties that determine how much of the soil is explored and how easily nutrients can move to roots. Cultivations, cropping and organic manuring all have large effects on physical properties of soil, so they alter both the value of nutrient reserves and also fertiliser efficiency. Much is done to understand how soil conditions affect crop nutrition and to develop simple methods of measuring physical changes that appear important.

Nutrient reserves of soils, their reactions with fertilisers and their structures are all related to basic properties of soils that are determined by the parent materials and the ways these have been modified by soil-forming processes. As these properties are related to the mapping units recorded in soil surveys, we hope that fertilising can be made more precise by using soil maps. Work has therefore been started to relate the physical and chemical properties associated with soil classification to crop growth and to fertiliser effects.

Organic Manures and Soil Organic Matter

Farmyard manure experiments at Woburn. The series of annual experiments at Woburn started in 1960 to compare farmyard manure (FYM) and fertilisers was intended to measure only the effects of the nutrients in FYM, so a new site was used each year to avoid physical effects on soil from organic matter accumulating. Up to 1963 fertilisers and FYM gave equal yields of sugar beet and globe beet, but maincrop carrots given FYM yielded 27·5 tons of roots/acre, a little more than with fertilisers (26·2 tons). The main fertiliser tests were with N and K, but Na and Mg were also tested several times. The basal dressing of superphosphate on all plots supplied 1·5 cwt P_2O_5/acre; this amount is more than enough for sugar beet, but it is not known whether it is enough for carrots. In the 1963 experiment carrot tops grew better with FYM than with fertiliser for most of the season, but this difference decreased until at lifting top weights were almost identical (10·4 and 10·2 tons/acre from FYM and from fertilisers respectively); the earlier growth on the FYM plots, however, gave nearly 1·5 tons/acre more roots. (There was no corresponding difference in rates of top growth of sugar beet and globe beet between 1960 and 1963.) FYM increased the % P in very young carrot plants; whether because FYM supplied extra total P, or because the P was more soluble, is unknown. A microplot experiment was therefore started in 1964 to test superphosphate supplying 0, 1·5 and 3·0 cwt P_2O_5/acre (with basal NK fertilisers) to carrots, sugar beet and globe beet. The fertiliser treatments were compared with FYM alone and with FYM + superphosphate supplying 1·5 cwt P_2O_5/acre. Both amounts of fertiliser phosphate increased early growth of carrots; the extra growth from 3·0 cwt P_2O_5 was about

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twice that from 1·5 cwt P_2O_5, and the plants were larger and more uniform than those given FYM only. Phosphate fertiliser also improved carrots on the FYM plots so that they were indistinguishable from crops on the best of the fertiliser plots. Phosphate did not affect early growth of globe beet and caused only small increases with sugar beet.

TABLE 1

Effects of phosphate fertilisers and farmyard manure on carrots, globe beet and sugar beet at Woburn in 1964

Treatment/acre	Carrots, roots (tons/acre)	Globe beet, bulbs (tons/acre)	Sugar beet, sugar (cwt/acre)
NK fertiliser alone	14·8	15·2	74·7
NK + 1·5 cwt P_2O_5	16·4	15·5	81·4
NK + 3·0 cwt P_2O_5	18·7	15·7	82·0
FYM alone	17·2	11·8	80·8
FYM + 1·5 cwt P_2O_5	19·2	12·3	82·2

These results on early growth of carrot seedlings, and final yields of roots (Table 1), show that FYM improved growth of carrots in 1963 because too little fertiliser P was given; in 1964, when more P was given, FYM was no longer superior to fertilisers. The increase in final yield from P fertiliser with crops that have a long growing season is often proportionally much less than the effect on early growth; these results in 1964 with maincrop carrots suggest that P fertiliser may be even more important for early carrots. (Johnston and Warren)

Possible losses of ammonia from decomposing plant materials. It is often assumed that when plant materials such as grass clippings, or more bulky cover crops, decompose on the surface the nitrogen they contain enters the soil. There is no proof that this is so, and laboratory equipment was developed to measure possible losses of ammonia. A stream of moist air was drawn over samples of grasses and legumes; after 5–10 days ammonia was liberated, and this process continued for 2–4 weeks. From one-quarter to one-third of the N in fresh grass (containing 0·6 to 0·7% N in fresh material) was lost as ammonia; one-third of the N in fresh lucerne and two-fifths of the N in fresh clover was lost (the materials contained 0·8 and 1·0% N respectively). Similar results were obtained with each plant material, whether used freshly from the field or after storage at $-15°$ C. (Salt)

Changes in the amounts of soil organic matter in ley and arable farming systems. The two ley–arable experiments that began at Rothamsted in 1948 are used to study changes in soil organic matter in different farming systems. The Highfield Experiment began on an old grassland soil and, in all the rotations tested, organic matter has steadily diminished. The Fosters Field Experiment began on an old arable soil containing little more organic matter than the continuously cropped soils, treated with fertilisers only, of the Barnfield (mangolds), Broadbalk (wheat) and Hoosfield (barley) Experiments. Both Highfield and Fosters have 6-year cropping cycles. In the first 3 years the treatment cropping tested includes continuous leys of

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lucerne, grazed grass and grass cut for silage. These leys are compared with 3 years of arable cropping as a preparation for the second 3 years of test cropping (wheat, potatoes and then barley), which is uniform over the experiments. When soil organic matter was first measured all except two blocks in each experiment had run for more than one cycle of 6 years. Analyses for organic carbon (C) shown in the *Rothamsted Report* for 1958 (p. 42) are means for the *two blocks* (Highfield 9 and 12, and Fosters 6 and 11) where the effects of the first 6-year cycle could be obtained. Results in Table 2 show the effects of two cycles (12 years) of cropping for 6 blocks of each experiment on soil samples taken at the end of the arable test cropping in each rotation. On Highfield about one-third of the original stock of organic matter has been lost under continuous arable cropping. The average annual losses under the ley rotations are nearly as great as under all-arable cropping. They are:

	C %
All-arable	0·12
Lucerne	0·11
Grazed ley	0·10
Cut grass ley	0·11

On Fosters Field organic matter has changed little under continued arable cropping; there has been no gain in organic matter (relative to the all-arable rotation) from the lucerne ley and only small gains from grass leys that were grazed or cut. The amounts of extra organic carbon in the soils that resulted from leys in the rotation were:

	Gains in % organic carbon after 12 years of ley farming (all-arable cropping is taken as standard)	
	Highfield	Fosters Field
Lucerne ley	0·09	−0·02
Grazed ley	0·25	0·13
Cut-grass ley	0·16	0·09

A grazed ley was more effective than the cut-grass ley in increasing organic matter on Fosters Field and in lessening the loss on Highfield; 3 years of

TABLE 2

Amounts of organic carbon in the soils of the Rothamsted ley–arable experiments after 2 cropping cycles (12 years)

Measurements refer to the surface 12 in. of soil

	Highfield		Fosters	
	Carbon (%)	Loss (relative to permanent grass)	Carbon (%)	Gain (relative to arable)
Continuous treatment with				
Permanent grass	3·57	—	—	—
Reseeded grass	3·26	0·31	2·05	0·70
All-arable rotation	2·13	1·44	1·35	—
Ley-arable rotations: 3 years of arable crops after 3 years of				
Lucerne	2·22	1·35	1·33	−0·02
Grazed ley	2·38	1·19	1·48	0·13
Cut grass	2·29	1·28	1·44	0·09

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lucerne ley had effects on organic matter similar to those of 3 years of arable crops (these, however, included a 1-year ley).

Changes under reseeded grassland. At the beginning of the experiment some plots on both fields were sown with a permanent grass mixture. On Highfield the loss in organic matter from ploughing (and reseeding) the permanent pasture still persists (0·2% C after 6 years, 0·3% C after 12 years). On the old arable soil of Fosters Field "reseeding" has increased organic C by 0·7% after 12 years, a gain of nearly 50%. The amount of organic matter in soil carrying the rotation of arable crops in Highfield (2·13% C) is now only little more than in reseeded plots on Fosters (2·05% C).

These results are means from six blocks of the experiments; they resemble the 12-year results with the two blocks for which there are also results after one cycle of 6 years (the two periods are compared in Table 3).

TABLE 3

Comparisons of amounts of organic matter in soils of the ley–arable experiments on Highfield and Fosters Field after 6 years and after 12 years

(Measurements are for % organic carbon in the surface 12 in. of soil)

	Highfield (Blocks 9 and 12) Amounts after		Fosters (Blocks 6 and 11) Amounts after	
	6 years	12 years	6 years	12 years
Continuous treatment with				
Permanent grass	3·22	3·82	—	—
Reseeded grass	3·02	3·61	1·68	2·14
All-arable rotation	2·74	2·25	1·42	1·31
Ley-arable rotation: 3 years of arable crops after 3 years of				
Lucerne	2·75	2·29	1·56	1·33
Grazed ley	2·83	2·48	1·60	1·47
Cut grass	2·78	2·43	1·64	1·40
	Changes, relative to permanent grass at 6 years, after		Changes, relative to all-arable at 6 years, after	
	6 years	12 years	6 years	12 years
Continuous treatment with				
Permanent grass	—	+0·60	—	—
Reseeded grass	−0·20	+0·39	+0·26	+0·72
All-arable	−0·48	−0·97	—	−0·11
Rotation of arable with				
Lucerne	−0·47	−0·93	+0·14	−0·09
Grazed ley	−0·39	−0·74	+0·18	+0·05
Cut grass	−0·44	−0·79	+0·22	−0·02

Therefore the results after 6 and after 12 years can be used with reasonable confidence to compare changes between one and two cycles, as done in the lower part of Table 3. During the second cycle on Highfield organic matter in soil under permanent grass has increased by 0·6% C (presumably from manuring the pasture that was initially poor). The reseeded plots accumulated the same amount of organic matter but still had 0·2% C less

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than the enriched permanent pasture. On Fosters the reseeded plots gained 0·3% C in the first 6 years and 0·7% C in 12 years. The organic matter lost from the all-arable plots of Highfield was the same for each cycle of 6 years (0·5% C). The loss from plots with lucerne in the rotation was also the same during each cycle and nearly as great as from the all-arable plots. With grazed ley and cut grass in the rotation losses were a little less than for lucerne, but were the same size in the two periods. In the all-arable rotation on Fosters the second cycle had little effect. The rotations with lucerne, grazed ley and cut grass, which caused small gains during the first cycle (0·1–0·2% more C than with arable cropping), gave no further increases during the second cycle.

For practical purposes, after 12 years a system of 3 years of ley followed by 3 years of arable cropping has not on either field affected the amount of soil organic matter differently from a rotation of all arable crops. Having a ley in the rotation neither materially retarded the loss of organic matter in land that had been old pasture nor materially increased the amount in old arable soil. (d'Arifat and Warren)

Relationships of yields of wheat to changes in soil organic matter and nitrogen supply in ley–arable experiments. In both Highfield and Fosters yields of wheat, grown as the first of three test crops, have been greatly affected by the preceding arable crops and leys. In the early years of the experiment on Highfield, wheat did not respond to nitrogen fertiliser, but, as arable cultivation continued, responses to N have increased and now resemble those on the old arable soil of Fosters. Since 1961 a scale of fresh nitrogen dressings (from 0 to 0·9 cwt N on Highfield and from 0 to 1·2 cwt N/acre on Fosters) has been tested to value the extra nitrogen provided by the leys for the first crop after ploughing. The top part of Table 4 shows yields of wheat grown without nitrogen and the amounts of nitrogen they contained. In all recent years wheat after lucerne has yielded much more than wheat after grass leys or arable crops, about 25–30 cwt/acre more total yield (grain + straw) in each field, containing 0·24 cwt more N on Highfield and 0·4 cwt on Fosters. In contrast, total yields and amounts of nitrogen removed after grass leys resemble those after arable crops, but the grazed ley is consistently better than the ley that is cut and removed. (The grazed leys receive little nitrogen fertiliser and contain much vigorous clover; the leys for cutting were sown with grass–clover mixtures, but are given more N fertiliser, which depressed the clover.)

Differences in yields (Table 4) are not related to differences in soil organic matter caused by the histories of the fields or the cropping systems tested. Although the Highfield soil still contains nearly 60% more organic matter than the old arable field, grain yields in continuous arable rotation have been only 20% greater. Yields with the maximum N dressing tested (0·9 cwt N/acre on Highfield and 1·2 cwt on Fosters Field) are in the lower part of Table 4. These amounts were too little for maximum yields of straw in any rotation, or for maximum yields of grain in any rotation except that with lucerne, which gave maximum yield with 0·6 cwt of fertiliser N on Highfield and 0·8 cwt N/acre on Fosters Field. With adequate nitrogen, total yields (grain + straw) were almost identical on both fields, and in

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both the lucerne and the arable rotations. Total yields after both kinds of grassy leys were less than after a sequence of arable crops, even when the amounts of nitrogen fertiliser given were thought to be adequate. The behaviour of the wheat crops is not obviously related to measurements of

TABLE 4

Yields and nitrogen contents of wheat grown without N fertiliser and also with the largest amounts of fertiliser tested, average of 3 years, 1961–63

(All figures are in cwt/acre; grain and straw contain 15% moisture)

	Three-year cropping preceding the wheat			
	Lucerne	Grazed ley	Cut ley	Arable crops
	Crops grown without nitrogen fertiliser			
Highfield				
Grain	44·8	34·6	30·9	34·2
Straw	38·1	31·1	21·5	25·3
Total crop yield	82·9	65·7	52·4	59·5
Nitrogen in total crop	0·84	0·63	0·54	0·60
Fosters Field				
Grain	45·4	29·6	30·3	28·4
Straw	35·8	21·8	18·3	17·8
Total crop yield	81·2	51·4	48·6	46·2
Nitrogen in total crop	0·90	0·55	0·54	0·50
	Crops grown with the largest amounts of nitrogen fertiliser tested			
Highfield				
Grain	47·0	46·4	47·1	51·9
Straw	51·0	44·7	40·3	50·4
Total crop yield	98·0	91·1	87·4	102·3
Nitrogen in crop	1·14	1·03	0·94	1·10
Fosters Field				
Grain	52·6	43·5	42·4	50·1
Straw	48·2	40·4	40·3	46·6
Total crop	100·8	83·9	82·7	96·7
Nitrogen in crop	1·28	1·04	1·01	1·11

soil organic matter in Table 2 or to the changes shown in Table 3 that have occurred under the four rotations. Without N fertiliser best yields have been obtained after lucerne which has not increased organic matter on Fosters and has hardly checked the loss on Highfield. Small gains in organic matter in Fosters, and slower loss in Highfield, caused by the grassy leys, are associated with poorer wheat crops. Clearly, if changes in soil organic matter do affect wheat yields their effect is the reverse of traditional belief; rotations that increase organic matter give less wheat.

Differences in yield of wheat may reflect different amounts of N supplied to the crop from organic residues in the soil, and also the interactions of ley residues and fertiliser nitrogen. Table 5 therefore shows % N in grain and straw. Without fertiliser-N, grain after lucerne contained most N in both fields, and there was little difference between grain from the other rotations, but in both fields straw contained most N after the grazed ley. With the large dressings of N, grain from crops after lucerne still contained more N than grain in the other rotations; straw had the most % N after grazed ley, and least in the all-arable rotation. These figures suggest that

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the organic residues left in the soil by lucerne release nitrogen in ways that favour its accumulation in grain and increase yields of both grain and straw. Fertiliser-nitrogen can give yields of both grain and straw in the arable rotation as large as obtained after lucerne, but the wheat accumulates less N. Wheat after grazed leys accumulates N in the straw; presumably the N is released too late to increase grain yields. Wheat after cut-grass leys has yielded less than in other rotations, even when given the largest amounts of N, and the % N in the produce has exceeded that of wheat grown in the arable rotation.

TABLE 5

Percentages of nitrogen in grain and straw of wheat from Highfield and Fosters ley–arable experiments, average of 3 years, 1961–63

	Three-year cropping preceding the wheat			
	Lucerne	Grazed ley	Cut ley	Arable crops
	Crops grown without N fertiliser			
Highfield				
Grain	1·90	1·75	1·80	1·83
Straw	0·47	0·56	0·46	0·40
Fosters				
Grain	2·02	1·84	1·84	1·86
Straw	0·41	0·45	0·39	0·35
	Crops grown with N fertiliser			
Highfield				
Grain	2·25	2·06	1·97	2·03
Straw	0·70	0·75	0·60	0·54
Fosters				
Grain	2·33	2·23	2·20	2·15
Straw	0·59	0·62	0·58	0·51

Table 6 shows the extra N in the crops (grain + straw) receiving N fertilisers expressed as a percentage of that applied. From small dressings roughly half of the N was recovered, and differences in recoveries between the four rotations and the two fields were not consistent. But wheat after lucerne in both fields apparently recovered only a third of the largest dressing of N, whereas in the arable rotation it recovered more than half. Recoveries from the larger dressings in rotations including grass leys were less than recoveries in the all-arable rotation, particularly on Fosters. The shapes of the response curves suggest that crops after leys would have responded to even more N fertiliser than was given, suggesting that the residues of grass leys interfered with the uptake of the fertiliser.

How the rotations affect nitrogen economy is shown in the lower part of Table 6, where the mean gains in N from using the ley rotations are calculated. Wheat gains nothing from grass leys in Fosters field; in Highfield it lost N consistently from the cut ley, but gained slightly from the grazed ley. It gained substantially from 3 years of lucerne in Highfield and still more in Fosters. These effects were characteristic of the rotations; they persisted in the presence of fertiliser-nitrogen, though the gains diminished with the larger dressings. The average effects shown in Table 6 conceal large differences in individual years. In 1961 there were consistent losses of nitrogen from both fields where wheat followed either kind of grass ley;

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in 1963 there were sizeable gains after these leys. Also in 1963 wheat after lucerne gained much more N than in 1961.

TABLE 6

Effects of preceding cropping on the efficiency of fertiliser nitrogen given to wheat in the Rothamsted ley–arable experiments, averages for 3 years, 1961–63

N (cwt/acre) applied to wheat	Three-year cropping preceding the wheat: Lucerne	Grazed ley	Cut ley	Arable crops
	Extra N in wheat (grain + straw) as percentages of N added as fertiliser			
Highfield				
0·3	40	61	52	42
0·6	35	51	49	53
0·9	33	45	45	55
Fosters				
0·4	58	46	48	54
0·8	43	44	42	55
1·2	32	41	39	51
	Mean gain in N (cwt/acre) by wheat grown in ley rotations over wheat in all-arable rotation			
Highfield				
0	0·24	0·03	−0·06	—
0·3	0·23	0·08	−0·03	—
0·6	0·13	0·02	−0·09	—
0·9	0·04	0·07	−0·16	—
Fosters				
0	0·40	0·05	0·04	—
0·4	0·41	0·01	0·01	—
0·8	0·30	−0·04	−0·06	—
1·2	0·17	−0·07	−0·10	—

The leys grown in these experiments have altered the yield of wheat that followed them. The effects are not related to total organic matter in the soils, or to changes in gross organic matter caused by the treatments. They are related to the extra nitrogen released when lucerne leys are ploughed in; where grass leys preceded the wheat, their residues have often interfered with uptake of fertiliser nitrogen and lessened its efficiency. Both the size and nature of these effects can vary from season to season for unknown reasons. (d'Arifat and Warren)

Soil Structure and Nutrient Uptake

Experiments at Woburn. Experiments to try to improve the structure of the soil (which contains only 0·5–0·6% of organic carbon) on the sites of the old Permanent Wheat and Barley Experiments described in last year's Report (pp. 39–41) were continued. The most revealing work was with globe beet, which germinates badly in the Woburn soil. The effects of applying peat and a synthetic soil conditioner (CRD.189) on early growth and yield of beet in 1963 depended on the weather during the few weeks following sowing. In wet weather CRD.189 gave the best crop, but 90 cwt/acre of peat was nearly as good. In dry weather peat gave the best germination and yield; CRD.189 improved germination a little, but did not increase the yield of bulbs. There was no extra benefit when CRD.189

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was added to the peat. In 1964 the weather was variable and the two materials applied together increased yield by 3·5 tons/acre, whereas peat and CRD.189 given separately gave only small increases of 0·4 and 1·0 ton/acre respectively. Although germination *seemed* generally satisfactory, giving a full plant (nearly 125,000/acre) after singling, the plots with peat + CRD.189 produced more seedlings that grew faster. These results (Table 7) suggest that peat and CRD.189 have complementary effects on soil condition.

TABLE 7

Effects of soil conditions on early growth and yield of globe beet at Woburn in 1964

Treatment	Average seedling weight (g dry matter) 26 May	15 June	Yield of bulbs (tons/acre)
None	0·009	0·116	12·6
Peat	0·010	0·186	13·0
CRD.189	0·012	0·084	13·6
Peat + CRD.189	0·015	0·261	16·1

Maincrop carrots, in contrast with globe beet, germinate well on Woburn soil. In the first year of an experiment to increase organic matter in the soil by adding peat, applying it to the seedbed increased yields of globe beet, but digging in more peat gave no further increase. One dressing of 62·5 cwt/acre of peat applied in the seedbed in each year increased yield of the second-year maincrop carrots from 15·6 to only 16·0 tons/acre; there was a useful increase to 16·9 tons/acre where one dressing was given to the seedbed and another was dug-in in the same year. Doubling the amount dug-in increased yield to 17·1 tons/acre of carrots. (Johnston and Warren)

Effects of artificially compacting seedbeds for barley and globe beet. Immediately after globe beet and barley seed were sown, the seedbeds were compacted with a heavy rubber-tyred vehicle or with a Cambridge ring roller. At Rothamsted a heavy clay soil long under arable cultivation on Barnfield and a silty clay-loam on Pastures Field ploughed from an 8-year ley were used. At Woburn the experiments were on sandy loam on Stackyard Field; the site has been arable for many years and has little organic matter. The large-sized pores in clods of 1 in. diameter or more were lessened in volume by compacting, but the small pores in crumbs of 1–2 mm were unaffected. The effects of compaction on pore distribution became less with depth, and were negligible 8–10 in. deep. They were greater in the heavy than in the light arable soil, and the Rothamsted soil ploughed from grass showed little change below 3 in. deep. Barley germination was related to the amount of large pore space in the top 3 in. of soil; the critical density that interfered with germination was greater on the light soil. Compacting the light soil accelerated the formation after rain of a hard surface cap which restricted roots; similar capping in the heavy soil was relieved by the cracking caused by wetting and drying.

Compacting with the Cambridge roller did not lessen beet or barley yields on the heavy soils, but it did on light land. The greater compaction

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by the vehicle greatly lessened yields of both crops on the light soil and, to a smaller extent, on the heavy arable soil. Running the heavy vehicle over the soil ploughed from ley had little effect on barley, but lessened beet yields. Total uptakes of N, P, K and Mn at harvest were not related to compaction. However, the ratio of N:P in the crops (which other work shows is affected by changes in the accessibility of nutrients to roots) was related to compaction of the light soil but not with either of the heavy soils. (Kubota and Williams)

Soil aggregation. Ryegrass, kale and red beet grown in pots were used to measure uptake of N, P and K from natural and artificial aggregates. Uptake of nitrate was independent of aggregate size, but uptake of P decreased as aggregate diameter increased, so the N:P ratio in the crop increased correspondingly. The N:P ratio in ryegrass was less affected by aggregate size at the first two cuttings, presumably because the roots had penetrated into the larger aggregates. Yields decreased as aggregate size increased. (Cornforth)

In an attempt to assess the effects of disturbing soil structure existing in the field, a special tool holding a can was used to take soil cores 6 in. high and 4 in. in diameter from Harwood's Piece at Rothamsted. Dwarf sunflowers were grown in some of the samples as taken, and in others after they were air-dried, passed through a 2-mm sieve and the stones removed. Soil-moisture contents at wilting point were the same in sieved and undisturbed soil, but the sieved ones lost moisture faster during the first 4 days. By the end of the experiment stones and size of ped had clearly influenced root development, particularly in subsoils. There was a dense network of flattened and distorted roots where soil and stones met and roots had not penetrated large strong peds free from stones. Undisturbed samples taken from 6 to 12 in. deep had plough pans, which showed by many roots growing along the junction of ploughed and unploughed soil. (J. K. Coulter)

Rubber latex as soil conditioner. Glasshouse experiments similar to those made with synthetic rubber latex emulsion (*Rothamsted Report* for 1962, p. 46) were made with natural rubber latex emulsion. The two soils used, both from headlands and with unstable structure, were a clay loam (Barnfield, Rothamsted) and a sandy loam (Stackyard field, Woburn); latex was better for stabilising aggregates in the sandy soil against the slaking effect of simulated rain than in the clay soil. Latex increased germination of kale during the first 8 days, but 15 days after sowing the effects were small, and final establishment and the numbers of seedlings weighing more than 2 g were not affected. Yield of kale was increased on the clay but not on the sandy loam.

Field experiments with globe beet on these two soils compared natural rubber latex with the synthetic rubber emulsion used in experiments described in the *Rothamsted Report* for 1963, p. 41. Germination and yield were unaffected by treating the clay soil with either latex; applied as fine sprays to the sandy soil, both tended to seal the particles of soil together, so increasing the rigidity of the surface layer which was already liable to

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"cap" when wet, and yield was slightly less from treated than from untreated soil. The tilth of the clay soil was better stabilised against rain by the synthetic latex than by the natural latex.

After the beet crops were harvested, water-stable aggregates in the top inch of both soils were increased by the synthetic latex, in clay soil by 9% and in the sandy soil by 45%. The natural latex used had no such lasting effect, perhaps because it contained less rubber.

Although neither rubber latex greatly affected crop growth, this work indicates principles that may be important in developing soil conditioners. Where the tilth to be stabilised is coarse, as in many clay soils, making the aggregates very stable may cause the surface to dry too quickly and injure germinating seeds. Where tilth is very fine, as happens in sandy soils, an effective conditioner may bind the soil particles together to form an impervious cap. Conditioners applied on the soil surface can only assist germination and early growth. They cannot remedy bad structure deeper in the soil; nor do they replace the cultivations needed to form a good seedbed. (Williams)

Polystyrene waste as soil conditioner. Some soils lose structure and "pack" below the surface so that roots are impeded. They are improved by bulky organic manures that keep soil particles apart, and it seemed that other coarse materials might have similar effects. Hence, shredded expanded polystyrene waste was added to columns of an unstable clay-loam soil which were then slaked by percolating water; barley was then grown on the columns. Permeability of the soil was increased and settling after slaking decreased; both effects were proportional to the amount of polystyrene added, from none to 75% of the volume of the column. Barley yields were not increased by any of the rates of polystyrene tested and were least with 75%. Roots were most widely distributed with 75% of polystyrene, but weighed most with only 10%. Such inert wastes may be useful diluents for difficult soils, but shredded polystyrene is so light (0·01 g/ml) that it would be difficult to apply to field soils unless first mixed with moist soil. (Williams)

Volume of soil used by roots. The effects of soil volume on root growth and uptake of nutrients were again studied with plants in pots. As with oats last year, the uptake of mobile nutrients (like nitrate) was proportional to soil volume, whereas that of immobile nutrients (like phosphate) per unit volume of soil decreased as the volume of soil available to the roots increased. The weight of roots per unit volume of soil was more related to nutrient uptake per unit volume with immobile than with mobile nutrients. Ryegrass that was cut several times removed nitrate quickly from a large volume of soil, whereas more phosphate was removed by the later than the earlier cuts. Grass roots penetrated quickly to the bottom of the pots and used nitrate fully. Phosphate could not diffuse so quickly to the roots, so maximum uptake from the deeper soil had to wait until the roots had branched and explored the soil more thoroughly. With smaller volumes of soil, dense roots systems developed sooner and more P was taken up early in the experiment. The relationship between the N:P ratio in the plants

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and the soil volume depended on the species; the ratio in tomatoes increased more as soil volume increased than in kale. (Cornforth)

Attempts to measure the volume of soil exploited by plants were made in a field experiment with cabbages spaced logarithmically from 10 to 34 in. apart by the method described by J. A. Nelder (*Biometrics* (1962) **18,** 283). The depths roots penetrated were estimated by measuring soil-moisture losses with a neutron moisture meter. Two-thirds of the water available to the plants between field capacity and wilting point was taken down to 70 cm at the closest spacing and to 30 cm at the widest spacing in unfertilised soil, and down to more than 80 cm at the closest spacing and 70 cm deep at the widest spacing in the fertilised soil. The results suggest that plants did not explore all the available soil volume for nutrients, but that they explored a greater volume for water in fertilised than in unfertilised soil. The yield per plant increased from the closest to the widest spacing, but the spacing for maximum yield (and therefore maximum "explored" soil volume) was not reached. At the widest spacings the plants did not touch, so only nutrients and water could have limited growth; probably in 1964 water was most important; the closest spaced plants had 13% dry matter at harvest, the widest spaced only 8%. Dry matter produced per unit area decreased from the closest to the widest spacing (the ratio for these two spacings was 1:1·3). (J. K. Coulter)

Soil Classification and Fertility

Most large-scale maps (of 1 in. or more to the mile), such as are produced by the Soil Survey of England and Wales, show soil series as mapping units, and typical profiles are described in the accompanying Memoirs. Such information helps in planning land use, in selecting suitable crops, and with drainage and cultivation problems. But soil maps do not indicate fertility (i.e., productivity) or help in planning manuring unless detailed field experiments have been done on the soil series described. For maps to be permanently useful in crop nutrition work, the soil characteristics recognised in mapping units must be related both to results of fertiliser experiments and to measurements of chemical properties that are not easily changed.

The productivities of several soil series were measured by harvesting crops from plots in individual fields where two or more soil series had been mapped; this method eliminated differences from management, manuring and previous cropping. In one experiment adequately fertilised potatoes gave almost identical yields on Hanslope Series (Chalky Boulder Clay soil) and on Bengeo Complex soil on Fluvio-glacial sands and gravels. However, on the same farm sugar beet on Hatfield Series (from brick-earth) gave 59 cwt sugar/acre, whereas it gave only 36 cwt on the Bengeo Complex; both crops had the same fertiliser, thought to be enough for full yields. In a grass field the most hay (39 cwt dry matter/acre) was given by Charity Series, the least (30 cwt/acre) by Winchester Series, with Icknield Series intermediate. These soils are now being examined to try to explain these differences in productivity. It is hoped to separate moisture and nutrient relationships, and the effects of management and previous cropping, from

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the influence of soil genesis. Exhaustive cropping in pots showed large differences in potassium relationships; four cuts of ryegrass removed 256 ppm of K from Winchester Series soil but only 103 ppm from the Charity complex. Capacity to supply phosphate (assessed by Mattingly by plotting a P intensity measurement in 0·01M–$CaCl_2$ solution against P soluble in 0·5M-$NaHCO_3$) varied more with different soils in the same field than with the same soil type in different fields. (J. K. Coulter)

Soil productivity is affected not only by the amounts of nutrients already present but also by characteristics that determine whether nutrients applied by fertilisers are retained in useful forms, whether they become unavailable or whether they are readily leached. Fertiliser movement down the profile of a sandy podzol in the Forestry Commission Nursery at Wareham was measured. All the P supplied by superphosphate had been lost from the A horizon and had accumulated in the B_1 and B_2 horizons; in contrast, total P in the A_1 horizon was much increased where Gafsa rock phosphate or basic slag had been applied, but not in the B_2 horizon. Almost all the roots of Sitka Spruce transplants were confined to the A_1 horizon. The ends of some of the roots were thickened and white; possibly some toxic factor in the A_2 horizon prevented them penetrating more deeply, even during the dry summer of 1964. The bulk density of the 0–6-in. horizon was 1·34 g/ml, compared with 1·48 g/ml for uncultivated soil and 1·04 g/ml in plots on another section of the Nursery given 40 tons of hop and bracken compost since 1959. (J. K. Coulter and Bolton)

Experiments with Nitrogen Fertilisers

Alternative nitrogen fertilisers for spring barley. In continuing experiments comparing nitrates with ammonium sulphate, the fertilisers were broadcast on seedbeds to give 0·45 or 0·9 cwt N/acre and were tested with basal combine-drilled dressings of P or PK fertiliser; the responses to P were measured on additional plots. Early in May growth of barley given nitrates was much inferior to growth with ammonium sulphate; a top-dressing of 0·45 cwt N/acre was tested in three experiments to see if this would replace the nitrate-N that appeared to have been leached by above-average rainfall in March and April. Average grain yields from the tests (Table 8) showed no overall benefit from nitrate-N in 1964; this was because on one light gravelly soil, where nitrate was readily leached, ammonium sulphate gave 38 cwt of grain/acre and calcium nitrate only 32 cwt.

TABLE 8

Mean yields of grain (cwt/acre at 15% moisture content) from four barley experiments in 1964

Yield without nitrogen 21·9 cwt/acre

	Nitrogen applied (cwt/acre of N) to seedbed	
	0·45	0·90
Ammonium sulphate	32·6	38·0
Calcium nitrate	32·4	38·0
Calcium nitrate plus sodium chloride	35·9	39·5
Potassium nitrate	32·7	38·0
Sodium nitrate	33·6	38·8

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The effects of top-dressing with N are shown by the following figures, which are averages for the forms of N tested as seedbed dressings in the three experiments:

N tested as top-dressing, cwt/acre	N applied to seedbed (cwt/acre) 0·0	0·45	0·90
		(cwt of grain/acre)	
0·00	20·0	30·9	37·0
0·45	30·6	38·2	40·8

There were large increases from "Nitrochalk" given in mid-May. A divided dressing supplying altogether 0·9 cwt N/acre gave a slightly larger yield than an equivalent seedbed dressing in this wet spring. Applying 0·45 cwt N/acre as top-dressing in addition to 0·90 cwt N/acre on the seedbed gave nearly 4 cwt of extra grain per acre; in this group of three experiments grain yield was doubled by nitrogen fertiliser. In the simple test of 0·5 cwt P_2O_5 and 0·5 K_2O/acre responses to P and to PK were unimportant by comparison with response to N. Average yield without P or K was 35·0 cwt grain/acre, combine-drilling phosphate alone raised it to 36·8 cwt, and K with P gave only 37·2 cwt. (Widdowson and Penny)

Alternative fertilisers for grass. Urea nitrate gave slightly less yield from an established sward of grasses and clovers than ammonium nitrate or sulphate when all supplied 100 lb N/acre. Doubling the urea nitrate gave less grass than the single dressing, but doubling the other forms of N raised yields. Ammonium sulphate treated with "N-Serve" gave no more grass than untreated fertiliser. (Gasser and Penny)

Rates of uptake of N by cereals. Parallel experiments in the greenhouse and in the field tested ammonium sulphate and calcium nitrate with barley, wheat and oats; sample harvests were taken at intervals during the growing season. In pots the two forms of N increased yields equally; soil analyses showed that all the NH_4–N from ammonium sulphate had been nitrified 46 days after sowing. In the field both forms increased yields similarly except that at "dough" stage and at maturity nitrate at 50 lb N/acre gave more dry matter than equivalent ammonium-N. Forms and rates of fertiliser affected the N contents of the crop more than yields. A larger proportion of the fertiliser-N was recovered from the small than from the large dressing and, on average of crops, rates and sampling times, more N was recovered from calcium nitrate than from ammonium sulphate. Dry matter was produced fastest by all fertilised crops between 40 and 100 days after sowing, whereas N uptake was fastest between 20 and 60 days after sowing. (Gasser and Iordanou)

CD-urea. Work with crotonylidene di-urea (*Rothamsted Report* for 1963, p. 45) was continued with ryegrass grown in pots for 50 weeks and cut 10 times. The grass took up about a third of the N given, regardless of the amount given or how it was applied. When the fertiliser was mixed with one-quarter of the soil in the pot the first cuts contained more N than when it was placed at points 1 in. below the seed, but later cuts contained more N from the placed dressings. (Gasser and Jephcott)

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When incubated with soil in the laboratory only 10–14% of the CD-urea decomposed at 7° C in 24 weeks, and most of the mineral-N was released during the first week. At 25° C the amounts decomposed depended on the soil used and on the amount of fertiliser. Over three-quarters was decomposed in 24 weeks in an arable sandy soil. In a clay soil containing little organic matter two-thirds of a small, but only one-third of a large, dressing was decomposed. In a clay richer in organic matter about half of both small and large dressings decomposed. These results are for total decomposition in 24 weeks; the rate of decomposition at first differed considerably in the different soils.

Work with CD-urea was stopped because, although a slowly acting nitrogen fertiliser is needed, it does not promise to be useful. Decomposition at 7° C—a common field-soil temperature in spring—is too slow for it to be used. Even at 25° C—achieved only in glasshouses in Britain—it was not fully decomposed during the period required to grow a crop, and its rate of decomposition depended on soil type and amount applied in unpredictable ways. (Gasser)

"N-Serve." Preliminary work with the nitrification inhibitor 2-chloro-6-(trichloromethyl)-pyridine (the Registered Trademark of Dow Chemical Company is "N-Serve") was described in *Rothamsted Report* for 1963, p. 46. In 1963–64 "N-Serve" mixed with ammonium sulphate (at 1% and at 2% of the weight of N in the fertiliser) was tested in experiments with wheat at Rothamsted and Woburn.

At Woburn treated ammonium sulphate applied in the autumn gave 4½ cwt/acre more grain than untreated fertiliser, but not when applied in spring (Table 9). Applying the ammonium sulphate alone in spring gave more grain than did the autumn dressing with "N-Serve". Calcium nitrate applied in spring gave more grain than ammonium sulphate at 75 lb N/acre, but not at 150 lb N/acre.

TABLE 9

Yields of wheat grain (cwt/acre) in experiments testing ammonium sulphate treated with "N-Serve"

Fertiliser N applied (lb/acre)	Ammonium sulphate applied in: Autumn		Spring		Calcium nitrate in spring
	Treated	Untreated	Treated	Untreated	
	Woburn (yield without N, 17 cwt/acre)				
75	29	26	37	38	46
150	43	38	52	54	52
	Rothamsted (yield without N, 46 cwt/acre)				
50	53	51	52	52	52
100	55	54	57	56	56

At Rothamsted wheat followed potatoes given much fertiliser and yielded well without nitrogen. Neither at 75 lb nor 150 lb N/acre were there any significant differences between autumn and spring dressings, or between the forms of N that were tested, suggesting that nearly all the N (applied as ammonium sulphate) was retained in the soil through the winter. "N-

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Serve" had no significant effect on yield. The Rothamsted experiment did not provide conditions for testing "N-Serve". At Woburn "N-Serve" checked nitrification of ammonium sulphate and so lessened loss by leaching of nitrate, but it was far from being completely effective. A more efficient inhibitor will be needed to provide a practical means of preventing losses of N during winter. (Gasser and Penny)

Phosphate Fertilisers

A powdered magnesium ammonium phosphate and two sizes of granules, made by different processes, were compared with powdered triple superphosphate. The chemical composition of the products was the same, but their densities differed. One product (A) had granules twice as heavy as the same-sized granules of the other product (B). The percentage triple superphosphate equivalents shown in Table 10 were obtained by graphical interpolation. Powdered magnesium ammonium phosphate increased the growth of ryegrass in pots more than did equivalent triple superphosphate; at the first cut the response to both granular products was less with the larger granules; the less dense product (B) acted quickest. Response to the coarse materials increased at the later cuts. The results show how speed

TABLE 10

Percentage triple superphosphate equivalents of magnesium ammonium phosphate during the growth of ryegrass

	% triple superphosphate equivalents (powdered material $<0{\cdot}18$ mm as standard)	
Fertiliser granule size (mm)	First cut (27 days)	Total of 4 cuts (97 days)
Product A		
$<0{\cdot}18$	113	88
2–3	50	71
4–5	26	52
Product B		
$<0{\cdot}18$	108	92
2–3	95	78
4–5	62	70

of action can be changed by altering the size and physical properties of granules of a phosphate fertiliser that is sparingly soluble in water. The lighter product (B) may have released P faster because the granules were softer and broke more easily in the soil, or because more granules were needed to supply a given dressing. (Blakemore and Mattingly)

Slow-release Fertilisers for Conifer Seedlings

Conifer seedlings, which make much of their growth in the late summer, are often grown on light sandy soils where soluble salts are rapidly lost by leaching. Under these conditions "slow-release" fertilisers may have special merits, and the very wet spring and early summer of 1964, which probably aggravated leaching losses, gave a good opportunity for testing sparingly soluble sources of N, P and K. Because of the prolonged dry spell that followed, seedlings remained small.

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In experiments with Sitka and Norway spruce seedlings a PK compound fertiliser made from superphosphate and potassium chloride was compared with potassium dihydrogen phosphate and potassium metaphosphate; all fertilisers were applied in March before sowing. In a fourth treatment the PK compound was supplemented by potassium nitrate added in three summer top dressings. (All plots had basal dressings of "Nitro-Chalk" and kieserite; on the potassium nitrate plots the "Nitro-Chalk" dressings were correspondingly decreased.)

At the end of June plants treated with potassium metaphosphate were greenest and most vigorous; they remained best throughout the season, closely followed by plants given potassium nitrate. Seedling tops were analysed at four times between early July and November. The % P in plants given metaphosphate consistently exceeded % P in plants given other fertilisers. Comparing the PK fertilisers only, % K in the plants was always least where PK compound only was given; % K in plants from other plots increased in the order: potassium dihydrogen phosphate, PK compound plus potassium nitrate, and potassium metaphosphate. By November plants on the potassium nitrate plots had overtaken those given potassium metaphosphate. Table 11 shows measurements made at the end of the growing season and scores for colour in September. The two species behaved similarly.

TABLE 11

The effects of P and K fertilisers on 1-year seedlings at Wareham in 1964

	Rate of application (g element/ sq yd) P	K	Height (in.)	Dry matter of tops (mg/plant)	Colour* score	P (%) (in dry matter of seedlings)	K (%)
Sitka Spruce							
No fertiliser	0	0	0·8	53	3	0·11	0·43
Superphosphate only	9	0	1·0	78	4	0·18	0·28
PK compound (from super + KCl)	9	9	1·0	71	2	0·14	0·36
Potassium dihydrogen phosphate	9	12	1·0	81	1	0·15	0·58
PK compound + KNO_3	9	15	1·3	120	0	0·18	1·05
Potassium metaphosphate	9	12	1·5	136	0	0·23	0·86
Norway Spruce							
No fertiliser	0	0	0·9	68	4	0·10	0·30
Superphosphate only	9	0	1·2	96	4	0·16	0·24
PK compound (from super + KCl)	9	9	1·2	100	3	0·16	0·30
Potassium dihydrogen phosphate	9	12	1·4	122	1	0·12	0·41
PK compound + KNO_3	9	15	1·6	144	0	0·14	0·83
Potassium metaphosphate	9	12	1·7	151	0	0·24	0·70

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

Magnesium ammonium phosphate is sparingly soluble, and so has potential use as a slowly acting source of N, P and Mg. Because it supplies three nutrients, designing experiments to compare it with other materials is difficult while defining the shapes of nutrient response curves.

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Preliminary work in 1964 indicated some of the experimental problems but suggested that this salt may be a useful fertiliser on very light soils. In a second experiment with Sitka spruce a "standard fertiliser" consisting of "Nitro-Chalk", superphosphate, potassium chloride and kieserite was compared with a compost made from bracken and hopwaste (applied at 15 lb/sq yd) and with magnesium ammonium phosphate used at three rates. As much basal K as was supplied by the standard fertiliser was given with all rates of magnesium ammonium phosphate, but this fertiliser supplied more P and Mg at all the rates tested and a little more N at the largest. The plants on plots with the two larger rates of magnesium ammonium phosphate grew faster throughout the season than those on "standard fertiliser" or compost plots, but showed signs of severe potassium deficiency, reflecting the early loss of K by leaching. In height and dry matter the plants with compost were roughly midway between those with standard fertiliser and with magnesium ammonium phosphate, though much better in colour than either. Plants given compost and standard fertiliser had much smaller % P (at the last sampling date) than plants given magnesium ammonium phosphate. Plants given compost had much larger % K than those given any other treatment. (Benzian, Bolton and Mattingly)

Fertiliser Placement Experiments

Broadcasting or drilling NPK fertilisers for spring barley. Four experiments compared three NPK fertilisers of different composition and % N : % P_2O_5 : % K_2O ratios; these were 22:11:11 (with a ratio of 2:1:1), 18:18:9 (2:2:1) and 18:18:18 (1:1:1). Each fertiliser was applied to give 0·45 or 0·90 cwt N/acre and was either broadcast over the ploughed land or combine-drilled. At the double rate of manuring, divided dressings (part broadcast and part combine-drilled) were also tested. Two experiments were on Clay-with-Flints, one on chalky loam and one on gravelly loam. Combine-drilling the double dressing caused little check to early growth in this wet spring. On the two soils from Clay-with-Flints, fertilisers with $N:P_2O_5:K_2O$ ratios of 2:2:1 and 1:1:1 gave better early growth than did

TABLE 12

Mean yields of barley grain from four 1964 experiments comparing three NPK fertilisers broadcast and combine-drilled

Yield without fertiliser, 24·7 cwt/acre

	Fertilisers tested		
	22 : 11 : 11	18 : 18 : 9	18 : 18 : 18
	Yields of grain (cwt/acre containing 15% moisture)		
At 0·45 cwt N/acre			
All broadcast	36·3	35·4	34·8
All drilled	37·7	37·6	37·4
At 0·90 cwt N/acre			
All broadcast	40·0	41·3	41·0
Three-quarters broadcast, One-quarter drilled	41·7	41·6	42·8
Half broadcast, Half drilled	43·3	43·8	43·8
All drilled	43·4	44·0	44·0

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the 2:1:1 fertiliser, presumably because they supplied more P; on the other two soils early growth was similar with all the fertilisers. Yields from the different fertilisers did not differ consistently in any experiment, but drilling gave more grain than broadcasting in three of the four experiments. Drilling half and broadcasting half gave almost the same yield as drilling the whole of the double rate of fertiliser (Table 12). (Widdowson and Penny)

Residual Effects of Fertilisers

Fertilisers are now given to almost all arable fields in Britain, and most cash crops get much more than previously; Surveys of Fertiliser Practice show that the average given to some crops is as large as can be recommended. Crops rarely take up all of a fertiliser dressing, and the practice of some farmers to give more than is generally recommended is justified only if the residues lessen the amount of fresh fertiliser needed by subsequent crops or enhance the response to fresh fertiliser. To gain information on these points we have done many tests in recent years to value the reserves of P and K that have accumulated in soils of the Classical Experiments after long periods of continuous cropping and manuring, and have measured the residual effects of single dressings of fertilisers in conditions more representative of usual farming practice.

The effects of long manuring in the Agdell Experiment on responses to new fertiliser dressings. Microplot experiments with arable crops, made on the Exhaustion Land (*Rothamsted Report* for 1959, p. 238) and on Agdell (*Rothamsted Report* for 1960, p. 68), measured the value of the PK residues from fertilisers given during the old experiments. On Agdell one-half of each of the six old Rotation plots was used in this way; barley, potatoes and sugar beet were grown side by side each year for 3 years. The other halves were sown with grass intended to grow for longer and to exhaust the residues. The grass was given 0·8 cwt N/acre after each cut taken at silage stage. Italian ryegrass was grown for 2 years and then cocksfoot for 3 years; the grass extracted 35–55 lb more P per acre from the plots with PK residues than from plots without residues. These amounts (averaging 7–11 lb P/acre each year) came from soils containing 250–500 lb more total P/acre. Five years of grass also removed all the extra readily exchangeable K from the soils of the PK residue plots. Altogether the grass on these plots extracted 340–530 lb more K/acre, three times greater than the amounts of extra exchangeable K initially present, so two-thirds of the K taken up was from reserves of " fixed " K. Because the P and K removed by the grass crops lessened the residues in the soil, appropriate basal P and K fertilisers were applied in 1964 to ensure that further uptake of P was not restricted by shortage of K and uptake of K by shortage of P.

It was also intended to study the effects of grass on the physical condition of the heavy Agdell soil. When measurements of the uptakes from the PK residues were completed the grass was to be ploughed and arable crops, grown with appropriate NPK fertiliser treatments, compared with similar crops on the halves of the old Rotation plots not sown with grass. Earlier results with barley on microplots on the halves without grass showed

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seasonal differences in the effects of the P residues, which seemed attributable to physical conditions of the seedbeds (*Rothamsted Report* for 1961, p. 55).

Two results from the microplots with arable crops on the Exhaustion Land and Agdell indicated that the PK residues needed further study. The first was that potatoes made less use of the residues than other crops; none of the P residues supplied enough P for full yields. Therefore, in comparing results of soil analyses with crop responses to P fertiliser, it was not possible to determine the amount of soil P needed to give yields that would not be increased by a new fertiliser. Secondly, barley, potatoes and sugar beet yielded more on Agdell where PK residues were greater, even when new NPK fertiliser was given to both kinds of plots. Potatoes on the Exhaustion Land also yielded considerably more where there were K residues, but other crops did not. To study these effects in more detail the scheme involving new basal P and K dressings for the Agdell grass was expanded, and P and K fertilisers were increased to provide new and larger residues when the grass is ploughed. The same set of dressings was also given to the half plots not sown with grass, which will be fallowed until the grass halves are ploughed.

The severe winter of 1962–63 damaged the cocksfoot, so the land was ploughed in autumn 1963 and resown in 1964. The new dressings of P and K fertilisers were applied over the ploughed land in March (P_2O_5 at 4, 8 and 16 cwt/acre and K_2O at 2·5, 5, 10 cwt/acre) and Timothy was sown on 8 May. Large benefits from *all* amounts of the new P and K fertilisers showed as soon as the grass germinated, but the dry weather

TABLE 13

The effects of new dressings of P and K fertilisers on yield of Timothy newly sown on the Agdell Experiment in 1964

Yields of dry matter (cwt/acre)

Plot number and manuring in the old Agdell Rotation Experiment	*1964 treatments* New phosphorus (cwt P_2O_5/acre)			
	0	4	8	16
1 and 2 NPK	5·2	12·7	15·6	18·8
3 and 4 PK	1·4	8·3	9·8	11·0
5 and 6 nil	0	7·0	6·0	8·4
	New potassium (cwt K_2O/acre)			
	0	2·5	5	10
1 and 2 NPK	8·8	16·6	16·3	17·9
3 and 4 PK	5·3	9·6	14·3	10·0
5 and 6 nil	3·2	7·7	8·6	8·8

(In 1964 all plots had 0·8 cwt N/acre; those with fresh dressings of P received 10 cwt K_2O/acre, and those with fresh K had 16 cwt P_2O_5/acre).

after June checked growth and only one silage cut was taken. (Table 13 gives the average yields for the clover and fallow sections of the old Rotation Experiment.)

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Even with the most new P and K fertilisers given, productivity of the plots still differed and maximum yields on the old NPK plots were twice those on the old unmanured plots. On these NPK plots each extra amount of new P fertiliser increased the growth of grass, whereas on the unmanured ones yields with 8 and 16 cwt P_2O_5/acre were no larger than with 4 cwt P_2O_5/acre; similarly, new K at 2·5 cwt K_2O/acre increased yield by 4·5–8·0 cwt dry matter/acre and there was little further increase from 5 and 10 cwt K_2O. (Johnston and Warren)

Residual effects of NPK fertilisers given to potatoes on wheat. In one experiment in 1963 and two in 1964, wheat was grown following potatoes given no fertiliser or 5, 10 or 15 cwt/acre of a compound fertiliser containing 13% N, 13% P_2O_5 and 20% K_2O. The residues from these dressings were valued by fresh dressings of fertiliser (of the same N : P_2O_5 : K_2O ratio) applied for the wheat. (P and K were broadcast on the seedbed in autumn and the N was given in the spring; each of the four rates of manuring tested on potatoes was compared in all combinations with the three rates tested on wheat.) Table 14 shows that fertiliser applied for the potatoes greatly increased wheat yields, not that this was excessive, for the increase in tuber yield from the most used (2·0 cwt N, 2·0 cwt P_2O_5 and 3·0 cwt K_2O/acre) more than paid for its cost (*Rothamsted Report* for 1963, p. 48). The response by wheat to residues of the largest fertiliser dressing given to the potatoes ranged from 14·5 cwt grain/acre (with

TABLE 14

Mean yields from three experiments where wheat was grown after potatoes

Yields of wheat grain (cwt/acre at 15% moisture content).

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	31·4	35·3	38·4	45·9
5	43·5	46·2	47·9	45·9
10	47·1	46·6	49·5	49·4

wheat not given fertiliser) to 2·3 cwt grain/acre (with the wheat given fertiliser equivalent to 10 cwt/acre of 13 : 13 : 20). Wheat not given fertiliser yielded 46 cwt grain/acre where grown after potatoes that had received 15 cwt/acre of 13 : 13 : 20; after unmanured potatoes, wheat given the equivalent of 5 cwt/acre of 13 : 13 : 20 fertiliser yielded 44 cwt/acre. Therefore in the conditions of this test one-third of a large fertiliser dressing given to potatoes was apparently used by the following wheat crop.

Other recent experiments at Rothamsted also show large effects of residues from fertilisers applied for potatoes; even after wet winters they have increased yields of following crops. They have also raised the yield potential of the following wheat. Thus, Table 14 shows that wheat given 1·3 cwt N/acre (more than current recommendations) yielded 3 cwt/acre less grain where it followed potatoes given 5 cwt/acre of 13 : 13 : 20 than where it followed potatoes given 10 or 15 cwt/acre. (Widdowson and Penny)

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Residual effects of ammonium sulphate. An experiment was started in 1960 on clay-loam at Rothamsted to measure the effects of ammonium sulphate given for wheat on following potatoes, and of ammonium sulphate given for potatoes on following wheat (*Rothamsted Report* for 1962, p. 50). The wet autumn of 1960 prevented sowing winter wheat after the potatoes, so spring wheat was sown in 1961, but in 1962, 1963 and in 1964 winter wheat was used. Potatoes measured residues after wheat in 1961, 1962 and 1963. Table 15 shows that potato yields were increased little by ammonium sulphate given to the wheat, but that wheat yields were increased greatly by ammonium sulphate (0·75 and 1·50 cwt/N acre) applied for the potatoes, even when the wheat itself received 1·0 cwt N/acre. Nitrogen given to potatoes affected grain yields in the same way as one-third as much fresh N given to the wheat. (Widdowson and Penny)

TABLE 15

The residual effects of ammonium sulphate on wheat and potatoes

Fresh N given (cwt/acre)	N given to wheat (cwt/acre)		
	0·0	0·50	1·00
	Yields of total potato tubers (tons/acre)		
To potatoes			
0·00	6·3	6·3	7·0
0·75	10·2	10·7	10·8
1·50	12·6	11·8	12·6
	N given to potatoes (cwt/acre)		
	0·0	0·75	1·50
	Yields of wheat grain (cwt/acre at 15% moisture content)		
To wheat			
0·00	22·7	26·0	31·4
0·50	31·1	33·2	34·9
1·00	36·4	39·4	41·8

Fertiliser residues in a sandy podzol. The A_1, A_2, B_1, B_2 and C horizons of a podzol soil in the Forestry Commission Nursery at Wareham were taken from plots of an experiment testing N, P and K fertilisers and magnesium sulphate. Leaching is severe, and analyses were made to see whether nutrients accumulate in the lower horizons. The A_1 and B_1 horizons contained more exchangeable cations than the A_2 and B_2 horizons, reflecting differences in cation exchange capacities determined primarily by the organic matter content. Where K was withheld all the nitrogen fertilisers tested lessened exchangeable K in the A_1 and A_2 horizons, but increased it in the B_1 and B_2 horizons; the total amount of K in the profile was the same with all treatments. Where KCl was applied, ammonium sulphate lessened exchangeable K in each horizon, whereas "Nitro-Chalk" and crushed hoof meal lessened exchangeable K in the A_1 and A_2 horizons only. All the N fertilisers lessened the total amount of exchangeable K in the profile. A potassium balance sheet calculated from crop analyses over several years shows that, of the K applied, the crops have taken up 23%, 7% is retained in the soil in exchangeable form and 70% has been leached from the top 17 in. of soil.

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Exchangeable sodium was larger than exchangeable potassium in each horizon of all the plots, even those given an average of 66 lb of K annually for 15 years. In such soil with little base exchange capacity the composition of the rain could determine the relative Na and K contents of the soil; salt from the sea carried to the site by rain probably explains the large Na/K ratio in this soil, which is only a few miles from the Dorset coast.

Calcium was the dominant exchangeable cation in all plots and was much increased where phosphate fertilisers containing calcium had been given. Both ammonium sulphate and crushed hoof meal lessened exchangeable calcium significantly in the A but not in the B horizons. "Nitro-Chalk" maintained exchangeable calcium of the A horizons at the same amount as in the plots not given N fertilisers. (Bolton and J. K. Coulter)

Residual effects of phosphate fertilisers

Sandy soil at Wareham. The accumulation and loss of P from fertiliser in the Wareham experiment already mentioned was further studied. The Report for 1963 (p. 50) showed that ryegrass in the glasshouse yielded more on soils containing residues of rock phosphate or basic slag than on soils given equivalent P as superphosphate. 10%, 80% and 50% of the P added in the field between 1959 and 1963 as superphosphate, rock phosphate and basic slag, respectively, were retained by the soil (Table 16). The P from superphosphate was either in solution or in the fine silt and clay, whereas rock phosphate increased the P in all size fractions of the soil and over half of it was in the coarse and fine sand. Of the P retained from basic slag, two-thirds was in the silt and clay or was dissolved in water when the soil was dispersed for mechanical analysis. Soil samples taken in 1963 were cropped with ryegrass in the glasshouse for 4 months, which changed the P contents of each fraction of soil as shown in Table 16. When the P was originally from superphosphate the ryegrass took its P

TABLE 16

Phosphorus contents of fractions of Wareham soil and changes caused by growing ryegrass in a greenhouse experiment

(Parts per million of P)

Particle size (μ)	Phosphorus contents of soil: From superphosphate 1959	1963	From Gafsa rock phosphate 1959	1963	From basic slag 1959	1963	Loss of P in 4 months of cropping from soils with P added as: Super	Gafsa	Basic slag
2,000–200	8	11	26	42	10	23	4	8	11
200–75	8	4	65	100	18	17	1	46	8
75–20	4	7	20	62	17	33	3	39	17
20–5	18	17	23	38	22	38	2	5	0
5	4	21	6	48	5	29	15	29	12
Solution	22	28	23	27	29	48	26	23	43

from solution and from the fine silt and clay. Over half of the P in grass derived from rock phosphate residues came from the fine sand (200–20 μ); the remainder was mainly from the fine silt and the solution. Of the P taken up from soil given basic slag, nearly half was from soluble phosphate and the rest from all other fractions except the coarse silt. Because P

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leaches down the profile, this soil is useful for work with fertilisers of different solubilities. The work described on p. 56 suggests that potassium metaphosphate and magnesium ammonium phosphate (which are slightly soluble in water) are preferable on this soil to superphosphate (which is completely soluble and easily leached) or rock phosphate and basic slag, which are insoluble. (Mattingly)

Clay-loam at Rothamsted. Two experiments started at Rothamsted in 1959 (*Rothamsted Report* for 1960, p. 56) measure cumulative effects of superphosphate and residual effects of several other kinds of phosphates; mean yields/acre of the three crops grown in 1964 were:

Phosphate given (cwt P_2O_5/acre)	Potatoes (tons)	Barley grain (cwt)	Swedes (tons)
None	8·6	41	5·7
Superphosphate each year			
0·25	9·2	43	10·0
0·5	9·8	41	12·1
Residues from 3·0 cwt P_2O_5 given in 1959 (mean of 7 fertilisers)	8·6	43	11·0

Barley yields were satisfactory without phosphate since 1959 and were not increased significantly by fresh dressings or by residues. Potatoes made no use of residues from 3·0 cwt P_2O_5 given in 1959, but yields were increased by the direct and cumulative effects of superphosphate given at 0·5 cwt P_2O_5/acre for the last 5 years. Swedes made good use of residues of P on these slightly acid clay soils and 3·0 cwt P_2O_5 given 5 years ago gave yields intermediate between those given by annual fresh dressings of 0·25 and 0·5 cwt P_2O_5/acre. Superphosphate, nitrophosphate, potassium metaphosphate, basic slag and Gafsa rock phosphate all had similar residual effects. (Mattingly)

Reference Plot Experiments

Long-term rotation experiments (in microplots) were started at Rothamsted in 1956 and at Woburn in 1960 to measure crop responses and nutrient uptakes. The experiments are of the same pattern, but the crops are chosen to suit the two soils.

Woburn. The experiment is on a sandy loam derived from Lower Greensand (*Rothamsted Report* for 1960, p. 55). Responses to N, P and K fertilisers and to FYM are measured on a five-course rotation of barley, grass–clover ley, potatoes, oats and sugar beet and there are similar tests on blocks of permanent grass and of soft fruit. All the arable crops except the ley responded to N; the ley, the potatoes and the barley responded a little to P, but only when N and K were also given. Potatoes, permanent grass, sugar beet and the ley all responded greatly to K, but oats and barley only little. The responses to K have increased greatly with time. FYM at 20 tons/acre is tested each year with sugar beet and potatoes; the other arable crops grow on the residues of these dressings. Permanent grass and fruit receive FYM annually (at 10 tons/acre). Potato yields were slightly

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greater with 20 tons of FYM than with the largest fertiliser dressing tested (1·5 cwt N, 0·5 P_2O_5 and 2·0 cwt K_2O/acre); conversely, sugar-beet yields were slightly greater with this amount of fertiliser than with FYM. Yields of sugar beet and of potatoes were large only with both FYM and fertilisers. Yields of other crops may have been limited by lack of water and by diseases rather than by lack of nutrients.

The largest mean total yield of barley (grain + straw) at Woburn from any treatment on average of the years 1960–63 was 55 cwt of dry matter/acre; at Rothamsted barley given similar manuring in a similar rotation yielded 80 cwt of dry matter/acre.

Rothamsted. The experiment (*Rothamsted Report* for 1960, p. 55) was extended in 1960 to measure the effects of calcium, magnesium, sulphur and a mixture of trace elements on the yields of barley, grass–clover ley, potatoes, wheat and kale grown in rotation and fully manured with N, P and K fertilisers. The initial pH of the soil was 5·6; it was not limed. So far, yields have been large with NPK along, and the other nutrients tested have affected yield little, except that calcium (1·0 cwt CaO/acre each year) increased the yields of barley and of the grass–clover ley slightly. Magnesium, sulphur or the trace elements have tended to decrease yields. (Widdowson, Penny and Williams)

The Effects of Fertilisers on the Composition of Crops

Cation–anion relationships in crop nutrition. The first experiments on this topic, described in the Report for 1962 (p. 45), showed that the percentage of total N in Italian ryegrass governed ion uptake. The ratio (*R*) of sum of total cations : sum of total anions in the crop was better related to percentage organic nitrogen than to total nitrogen. Recent glasshouse experiments with Italian ryegrass grown in 10 soils of different pH and texture showed that, at equal percentages of organic N, *R* values were increased by increasing soil temperature, but were lessened by increasing light or water. There were similar, but not identical, relationships for the roots and for the tops. (Cunningham)

The effects of fertilisers and "weather" on nitrogen fractions and soluble carbohydrates. Work described in the Report for 1963 (p. 54) showed that soil temperature affected the nitrogen and carbohydrate fractions of plants. The experiments were extended to find how other weather conditions (water and light) affect these fractions. In one experiment done in the glasshouse during June 1963, Italian ryegrass grown for 25 days was supplied with 6 rates of N, tested as both nitrate and ammonium (nitrification of ammonium was prevented by treating the soil with "N-Serve" (p. 54)). Three light intensities were produced by covering two-thirds of the grass with screens that transmitted 68% or 44% of the daylight. Total N in the grass increased more with nitrate than with ammonium. Soluble N was more with nitrate than with ammonium and was increased by shading. The organic fraction of the soluble N was increased by increasing amounts of ammonium fertiliser and by shading; this fraction was much less in

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grass given nitrate-N and was decreased by increasing N or by shading. Only when given nitrate fertiliser did the grass contain much free nitrate; the fraction was increased by increasing nitrate and by shading. Grass receiving 500 ppm of nitrate-N and 44% of normal daylight had two-fifths of its total nitrogen as nitrate. Amide-N, particularly as asparagine, and α-amino N, were increased by ammonium fertilisers and by increasing N or by shading. Increasing the nitrogen and shading both lessened soluble carbohydrates in grass; the effects of light were more with ammonium fertiliser than with nitrate.

In an experiment with Italian ryegrass during August–September 1963 the percentage of total soluble nitrogen was greater at larger water tensions with ammonium but not with nitrate fertiliser. In grass given nitrate fertiliser nitrate-N accumulated only when 200 ppm or more of N was given and, with these quantities, increasing water tension decreased nitrate-N in the grass. Soluble organic nitrogen increased in the drier regimes with ammonium-N but not with nitrate. (Nowakowski and Cunningham)

Effects of Formalin on the Yield of Spring Wheat

The light sandy loam at Woburn has been used for arable crops for many years, and cereals yield well only when given much N-fertiliser. However, lack of N is not the only problem, for some crops of wheat and barley that promise well in spring deteriorate in late May or early June. This is particularly likely with generous nitrogen manuring and when this period is drier than usual. The trouble, which we call "scorch", is associated with the presence of fungi causing foot rots. Affected crops benefit little from rain later, and many plants shrivel and the ears do not emerge. "Scorch" greatly complicates interpretation of results of fertiliser experiments, and in collaboration with D. B. Slope (Plant Pathology Department) its causes were sought by: (1) partially sterilising the soil with formalin; (2) adding nabam (a fungicide) to the soil; (3) watering at the critical period; and (4) giving different amounts of nitrogen. Each of these factors was tested in all combinations. The crop was sampled every 2 weeks from mid-May to mid-July; the weight, nitrogen and nitrate-N content of the plants were measured and the incidence was estimated of soil-borne diseases, principally brown foot rot and take-all, and of the cereal root eelworm *Heterodera major*. Watering was such that, with the rain that fell, the crop had 1 in. of water each week.

Although the experiment failed in its main purpose, for "scorch" did not occur on any plots, probably because the spring was wet and brown foot rot was not prevalent, the results from applying formalin were striking.

Table 17 shows that formalin doubled the grain yield and almost doubled the straw, whereas nabam increased grain and straw yields by less than 1 cwt/acre. Water increased both grain and straw yields by 6 cwt/acre, and additional nitrogen increased the grain by 6 cwt/acre and the straw by 13 cwt/acre. There was little advantage from applying more than 1·2 cwt N/acre.

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TABLE 17

The mean effects of formalin, nabam, nitrogen fertiliser and water on spring wheat at Woburn in 1964

Yields of grain and straw in cwt/acre at 15% moisture content

	Formalin		Nabam		Nitrogen (cwt/acre)			Extra water	
	Without	With	Without	With	0·6	1·2	1·8	Without	With
Grain	15·4	30·8	22·8	23·4	19·2	24·9	25·1	20·1	26·0
Straw	25·3	44·8	34·8	35·3	27·9	36·6	40·7	32·0	38·1

Table 18 examines the effects of water, formalin and nitrogen fertiliser averaging the nabam treatment. The minimum and maximum yields without formalin were 9 and 23 cwt/acre; equivalent yields with formalin were 26 and 37 cwt/acre. The response to water was greater where formalin was also given and was increased also by nitrogen. The response to nitrogen was not consistently affected by formalin, but was increased by water. The response to formalin was decreased by nitrogen, whether or not water was given, but was increased by water. Further observations on the experiment are in the report of the Nematology Department (p. 150), and suggest that formalin mainly acted by its effect on the take-all fungus and cereal root eelworm. (Widdowson and Penny)

TABLE 18

The effects of formalin, water and nitrogen fertiliser on wheat yields at Woburn in 1964

cwt of grain/acre at 15% moisture content

	Without formalin		With formalin	
N (cwt/acre)	Without water	With water	Without water	With water
0·6	9·1	11·6	26·3	29·9
1·2	15·1	18·3	29·1	37·2
1·8	14·8	23·4	26·5	35·8

Effect of Beryllium on Kale

Yields of kale and ryegrass were increased by beryllium (*Rothamsted Report* for 1963, p. 61), and the effect was further studied with "thousand-head" kale grown in pots on the two calcareous soils used before, a calcareous Rothamsted clay loam and an acid sandy loam from Woburn. Beryllium at 40 ppm by weight of soil in the pots again increased growth significantly in the calcareous Hertfordshire soil used in 1963, but had no effect on the other two calcareous soils and greatly damaged plants on the light acid soil. Applied to seedlings on all soils, beryllium caused necrotic spots on the cotyledons. Dressings applied to the soil for mature plants grown in the calcareous soils caused similar symptoms on the older leaves; these effects were transient. Leaf symptoms persisted in plants grown in the acid soil, and plants were stunted and roots grew slowly.

In culture solutions containing different concentrations of beryllium, growth was restricted by 5 ppm Be, which halved the rate of root growth of mustard seedlings without Be.

Obviously, beryllium can be very toxic to crops growing in acid soils

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(most Be compounds become less soluble as pH increases), and the reason for it stimulating growth of kale seedlings in the light calcareous Hertfordshire soil is puzzling. A similar effect was described by M. B. Hoagland (*Archs Biochem.* (1952) **35**, 249–258), with tomato plants grown in culture solutions containing less than 2 ppm Be; the solutions were alkaline and deficient in Mg, but there was no evidence that Be replaced Mg as a major nutrient, and Hoagland concluded that Be increased growth of mustard seedlings because it modified the behaviour of an enzyme. (Williams)

Phosphorus in Soils

Changes in soil phosphate potential on cropping. The monocalcium phosphate potential of soil ($0{\cdot}5pCa + pH_2PO_4$) was closely related to growth of ryegrass in pots in the glasshouse during the first few weeks after sowing (*Rothamsted Report* for 1959, pp. 44–45; for 1962, pp. 62–63); thereafter phosphate potentials fell rapidly as cropping continues (*Rothamsted Report* for 1957, pp. 59–60). Experiments were begun to follow magnitude and rate of change of potentials during exhaustive cropping of different soils and to see whether soil surfaces remain in chemical equilibrium with the soil solution during cropping. Methods developed by Fordham (*Aust. J. Soil Res.* (1963) **1**, 144–156) and by White and Beckett (*Pl. Soil* (1964) **20**, 1–16) were used in which soil is shaken with phosphate solutions in $0{\cdot}01M$-$CaCl_2$ solution, and the concentration at which P is neither taken from solution nor released from soil is found by graphical interpolation. Six successive harvests of grass were grown on soils from Rothamsted and Woburn. In both soils the phosphate potentials (I), determined after 2 hours equilibration, decreased linearly with the amounts (Q) of P removed by the grass per unit weight of soil. The gradient of the I/Q relationship was twice as great with Woburn as with Rothamsted soil, showing that the Rothamsted soil has greater and longer-lasting buffer capacity. The cropped soils at each harvest seemed to be in equilibrium, and their phosphate potentials did not change appreciably when they were stored moist for 3 months after cropping. (Webber and Mattingly)

Cations in Soils

Distribution of cations in soil fractions. Top soil from Barnfield headland (Batcombe Series) was mechanically fractionated according to the International scale, and the total cations in the fractions were measured after removing exchangeable and dilute-acid soluble cations by leaching with $0{\cdot}25N$-HCl. The clay fraction contained more total magnesium and potassium than the silt and sand fractions but less sodium and calcium. J. A. Catt (Pedology Department) showed that the fine sand contained about 7% of felspars, which could account for most of the sodium and calcium in this fraction. Previous mineralogical analysis of Rothamsted soils of this series (*Rothamsted Report* for 1960, p. 78) showed relatively large proportions of felspars in the fine sand fraction of the topsoil. (Bolton)

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Field experiments on potassium, magnesium and lime. Long-term experiments with similar designs were started at Rothamsted and at Woburn in 1960 to test potassium and magnesium fertilisers and to explore their interactions. In both experiments soil K has been depleted where none has been applied, and most crops now respond well to K fertilisers. Magnesium has not increased yields at Rothamsted, but some crops have given small responses at Woburn, where changes in exchangeable Mg in the topsoil after 4 years of cropping correspond closely to values calculated from the amounts of Mg applied, crops uptakes and the content of exchangeable Mg in soil before the experiment started. The potassium taken up by crops during 4 years exceeded the sum of the amount applied and the decrease in exchangeable K, by 230, 130 and 24 lb/acre respectively on plots that receive none, 95 and 170 lb K/acre each year. The extra K must either have been released from non-exchangeable sources or have been taken from the subsoils. (Bolton)

Exchangeable potassium in soils and clay minerals. Adsorption isotherms for five soils having from 28 to 42% of clay and for bentonite and vermiculite were measured by isotope dilution techniques in "double-label" experiments. At 25° C K ions were absorbed in preference to Na ions by all the materials used. The selectivity of K adsorption varied with the K : Na ion ratios in solution; for the soils it was maximal at 0·3, for vermiculite at and above 0·7; montmorillonite had least preference for K, and the selectivity for K as compared with Na did not change over the range of ratios of the two ions. When Ca was present instead of Na, Ca ions were selectively absorbed for all K : Ca ratios in all but one of the soils. Of the soils and minerals used, montmorillonite absorbed Ca most strongly. These conclusions on selective adsorption at 25° C were also generally true at 50° and 75° C.

Isotopically exchangeable potassium generally increased with temperature increase in both soils and minerals. At large K : Ca ratios in solution isotopically exchangeable Ca in the soils decreased a little, or remained unchanged, with increasing temperature; large decreases occurred at small K : Ca ratios. In montmorillonite, and particularly in vermiculite, exchangeable Ca increased with temperature. Total isotopically exchangeable ions (K plus Ca) decreased as temperature increased from 25° to 50° in both soils and minerals. (Deist and Talibudeen)

Potassium reserves in British soils. Thirty-four soils chosen from fertiliser-treated plots of the Rothamsted Classical Experiments and 26 soils from other parts of England (*Rothamsted Report* for 1963, pp. 58–59) were cropped with Italian ryegrass in pots. The grass was cut every four weeks when the soil solutions were also analysed. The yield from soils poor in K fell during the whole cropping period; soils rich in K maintained yield for the first three or four cuts, but less grass was produced at later cuttings. The amounts of yield accumulated after three and after seven cuts tended to be proportional to the potassium intensities of the uncropped soils $\left(I_0 = -\log \frac{(\mathrm{K})}{\sqrt{(\mathrm{Ca})}}\right)$, although yields from soils of similar intensities differed

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considerably. Soils rich in organic matter and with large K intensities gave larger than average yields; the reverse was true for soils with small intensities. Soils with much clay ($<2\ \mu$) generally gave larger yields, which were not affected by the proportion of the clay that was finer than $0{\cdot}2\ \mu$. % K in the ryegrass was most in the first cut, fell to a minimum at the third or fourth cut and was constant at later cuts, although yield decreased.

The potassium intensities in the soils varied during cropping according to the original level. In soils with large intensities, values fell rapidly until the fourth cutting and then slowly. In soils with small intensities, values were minimal after the second cut, and recovered later—almost to the original value at the fourth cutting. Changes in potassium intensities in cuts after the fourth, and their actual magnitudes, were similar in almost all the soils. The intensity after the seventh cut averaged 5×10^{-4} for 59 soils; one soil (Harwell series) was outstanding in having a value of 16×10^{-4}. Intensive cropping for four months therefore brought soils of very different initial K-status to the same intensity, although the amounts of K removed during this time ranged from 0·2 to 2 m.e. of K/100 g soil (i.e., from about 80 to 800 ppm).

Changes in yield in relation to changes in intensity were used to value potassium "buffer capacity" during cropping. The 20 soils rich in K had small capacities up to the fourth cut and large capacities thereafter; for this group capacities measured in the pot experiment were well related to laboratory measurements, $C_L = \frac{dQ}{dI}$, where Q is the exchangeable K in the soil and I is its intensity (although the laboratory values were twice as great). The two measurements of capacities were *not* well related in the group of 40 soils poor in K. The K intensities of the soils before cropping varied inversely with laboratory values for the "buffer capacity", suggesting that this measurement is related to exchangeable K and not to the properties of the rest of the K in the soil. (Dey and Talibudeen)

Potassium relationships in soils of the Rothamsted Classical Experiments. The experiments described in preceding sections show that the potassium characteristics of soils from the different Classical Experiments at Rothamsted with arable crops were very similar for plots that have had comparable manuring. They are summarised in Table 19. The potassium intensities (I_0) measured before cropping in the glasshouse soils that receive K (but no N), or FYM, were roughly 10 times greater than those of soils having no fertiliser or N fertiliser only. Plots treated with NPK fertilisers had K intensities only slightly larger than those of unfertilised plots, presumably because the large crops produced remove most of the potassium applied.

In seven cuttings of grass the total K (in ppm) removed averaged about:

200 from field plots given no fertiliser or N only;
400 from plots given NPK fertiliser each year;
over 800 from plots given K or PK fertilisers each year, or FYM.

Two-thirds of these total quantities were removed in the first three cuts. Whatever the initial value, the K-intensities of all plots were similar after 28 weeks of continuous cropping (and seven cuttings). The buffer

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capacities (C_L) of soils from plots receiving no fertiliser or N alone were large; those of the PK- and FYM-treated plots were small, and those of the NPK-treated plots were intermediate. This illustrates the inverse relationship between I_0 and C_L on the same soil and emphasises that C_L is primarily a function of the proportion of the total exchange capacity that is occupied by K and is not a basic property of the soil independent of its manuring and cropping history. On plots with comparable manuring C_L varied much between the different Classical Experiments, suggesting that the soils are at different points on the K-adsorption isotherm. (Dey and Talibudeen)

TABLE 19

Mean intensities and capacities of potassium in soils and yields of K in ryegrass grown in pot experiments on soils from the Rothamsted Classical Experiments on arable crops

(All values are averages for several soils from different experiments)

Continued treatment in the field	K Intensity $\times 10^{-4}$		Initial capacity $\times 10^{-3}$	Total yield of K in ryegrass as ppm K in soil	
	Initial	After 7 cuts	(C_L)	In 3 cuts	In 7 cuts
None	14	4	162	145	217
NH_4–N	11	5	152	97	148
NO_3–N	14	4	250	122	193
NPK	19	4	140	223	352
K or PK	129	5	103	520	840
FYM	212	5	45	563	903

Apparatus and Experimental Methods

Atomic absorption spectrophotometry. An atomic absorption spectrophotometer was built using the design of G. F. Box and A. Walsh (*Spectrochim. Acta* (1960) **16**, 255–258). The power pack for the tube and the supply for the photomultiplier and amplifier were made as described; the hollow cathode discharge tubes, monochromator, photomultiplier valves, atomiser and spray chamber were all bought. The equipment is simple, costs little and is dependable.

Much was done to develop a satisfactory burner arrangement. A cool air/town-gas flame had the advantage of a simple emission spectrum, but was insensitive and allowed other elements present to interfere. These difficulties were overcome by improving atomisation and increasing the efficiency of converting test solution to aerosol. This was done by preheating both air and gas supplies, modifying the atomiser and building a special burner. These changes made the instrument seven times more sensitive and raised the efficiency of atomisation to 90% (two other bought spectrophotometers had efficiencies of only 7 and 12%). The limits for determining three elements investigated (on the basis of a galvanometer scale deflection of 5%) were (in ppm of the test solution):

Magnesium	0·01
Zinc	0·05
Copper	0·125

When determining magnesium in solutions derived from plant materials or soil, interference was eliminated by adding 300 ppm of strontium.

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Other elements present did not interfere with the determination of zinc and calcium. (Rawson)

Flame spectrophotometer. Methods were developed for using a Unicam S.P. 900 flame spectrophotometer to determine K, Na, Ca and Mg, particularly in extracts from plant ash. For each element, radiation buffers were developed to prevent mutual and background interferences. Phosphate ions suppress Ca emission in pure solutions, but adding lanthanum chloride prevented this. Analyses for these four cations agreed well with results obtained by other methods, both with extracts of plant ash and with ammonium acetate leachates of soils. The instrument is very sensitive and is particularly useful for determining traces of cations present in soil solutions. Calcium emission (4,227 Å and 6,203 Å lines) was suppressed by large concentrations of aluminium; this was avoided by estimating calcium in the presence of 250 ppm of lanthanum (as chloride). 0·02 ppm Ca could be measured in solutions containing 2·7 ppm of Al. (Salt)

Determining small quantities of aluminium. Several reagents were compared for determining Al in solutions containing less than 1 ppm. The scale of sensitivity was eriochrome cyanine R (ECR) $>$ aluminon $>$ chrome azurol S (CAS) $>$ pyrogallol red (PR); the intensity of the reagent blank was in the order PR $>$ ECR $>$ CAS $>$ aluminon. Aluminon was the best reagent for measuring Al concentrations of $<$1 ppm (although batches from three different sources gave different results) because the intensity of the coloured Al complex was linearly related to the Al concentration in the test solution; with the other reagents this was not so.

Much smaller concentrations of Al ($<$0·05 ppm) were measured by the fluorescence of the Al complex with salicylidene-*o*-aminophenol (using a fluorimeter attachment on the Unicam SP500 spectrophotometer). Other workers have stated that iron and other elements interfere only when present at $>$5 ppm when the Al concentration was 0·01 ppm. We found that Fe concentrations $>$0·01 ppm interfered, but that all interference from Fe was suppressed by adding 0·1% of thioglycollic acid to the reagent. pH values below 5·8 decreased the intensity and, more seriously, the stability of the fluorescent complex; stable pH and therefore fluorescence was obtained by adding a 2*M*-acetate buffer to the reagent. After standing 40 minutes (away from direct sunlight) the fluorescence was stable for several hours. (B. S. Coulter and Talibudeen)

Determining total phosphorus in soils. We have for long determined total P by digesting soils with boiling 60% perchloric acid. Because of the risk involved (occasional explosions have been reported when perchloric acid is heated, and some of these remain without explanation) a fusion method was tested. Soil is fused with Na_2CO_3 in a platinum crucible; the melt dissolved in water and P estimated (after neutralising with H_2SO_4) with an ammonium molybdate–ascorbic acid reagent (D. N. Fogg and N. T Wilkinson, *Analyst* (1958) **83**, 406–414). Any silica present did not interfere. In the arable soils examined results by this method are 30–70 ppm P more than by the perchloric acid method; this represents an increase of

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about 5–10% in the total P content. Larger increases (15–30%) were obtained when the method was used on sandy soils from Forestry Commission Nurseries. (Mattingly)

Measuring soil pH. Suspensions of soil in 0·01*M*-$CaCl_2$ had constant pH values during the first 8 hours after being made. When shaken for up to 10 days pH values increased by as much as 0·5 unit; the larger increases were with the more acid soils. Soils from limed plots of the Park Grass Experiment, which originally had pH above 6·5, decreased slightly in pH during long shaking. Adding thymol or toluene–chloroform mixtures did not alter these pH changes, which were, however, increased when organic matter was removed by treating with hydrogen peroxide. To avoid changes that occur with time, pH values measured in 0·01*M*-$CaCl_2$ solutions should be completed within 8 hours of making the suspensions. In other work pretreatment with sodium hexametaphosphate was found to give misleadingly low values because hydrogen ions were released when the calcium complexes formed. (B. S. Coulter and Talibudeen)

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