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F. V. Widdowson and A. Penny

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Yields and N, P and K Contents of the Crops Grown in the Rothamsted Reference Experiment, 1956–70

F. V. WIDDOWSON and A. PENNY

The experiment, begun in spring 1956, measures the effects of N, P and K fertilisers and of FYM on five arable crops on very small plots (0·00128 acre) in Great Field IV, previously under grass for many years. After removing the turf, the plots were marked out and the soil on each plot sampled. The soil is a clay loam over Clay-with-flints, was acid originally (*c.* pH 5·6), but was limed in 1956 and again later; it contained little P soluble in $NaHCO_3$, or exchangeable K.

The crops chosen were typical of those grown on similar soils: wheat ('spring' in 1956, 'winter' subsequently), kale, spring barley, grass–clover ley and potatoes. Each crop was grown each year in the above sequence. In 1957 a strip of the original permanent grass was included in the experiment and the same tests made on it. In 1960 a similar experiment was begun on a sandy loam over Lower Greensand at Woburn, Beds; oats and sugar beet (crops more suited to that soil), replaced the wheat and kale grown at Rothamsted. The results from the first two cycles of the experiment at Woburn were described in Part II of the *Rothamsted Report for 1971* (Widdowson & Penny, 1972).

N, P and K (0 and 1) were tested factorially on each crop, and also N_2, but only with P and K. Farmyard manure (D) was tested alone and with fertilisers (DN_1PK and DN_2PK). Thus each block had 12 plots, grew one of the five crops in sequence and was given fertilisers cumulatively. The third five-year cycle of the experiment ended in 1970.

Each year the crops were weighed, sampled for dry matter and analysed for N, P and K to calculate (1) the amounts of N, P and K removed by the crops, (2) the apparent recoveries by the crops of the N, P and K added in fertilisers and in FYM, and (3) the balance between the amounts of N, P and K added in fertilisers and in FYM and the amounts removed by the crops in each five-year cycle of the experiment.

The yields obtained from the first cycle of the experiment were published by Widdowson, Penny and Cooke (1963) and from the second by Widdowson and Penny (1968). The amounts of N, P and K in the crops grown during the first cycle were published by Williams, Cooke and Widdowson (1963).

We give here yields from the third cycle and mean yields from all three. The amounts of N, P and K removed annually by each crop averaged over the three cycles (1956–70) are also given and selected results from the three cycles of crop yields and N, P and K contents are compared.

Because the leaves of potatoes grown in the Woburn Reference experiment showed Mg deficiency symptoms in 1967, each plot of potatoes there was split to test Mg (0 *v* 1) from 1968 onwards. In the Rothamsted Reference experiment only very mild symptoms were noticed in some lower leaves in 1967, but from 1968 each plot of potatoes also was split to test Mg.

Experimental method, 1966–70

Appropriate blocks were dug in late autumn after giving FYM for the potatoes and kale; FYM was spread on the permanent grass in early spring. N, P and K for barley, potatoes and kale was cultivated in before sowing. P and K for winter wheat was cultivated in before sowing and half of the N was broadcast in March and half in May. P and K for the ley and permanent grass was broadcast in winter; the ley was given all its

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N in spring, but the permanent grass was given one-third of its N for each of three cuts. Mg for the potatoes was given in the seedbed. Because barley grown with both N fertiliser and FYM residues often lodged and killed some of the under-sown grass and clover, the seeds of both were drilled between the rows of barley stubble in August from 1969 onwards. Methods of sowing the other crops and of harvesting all crops were described by Widdowson, Penny and Cooke (1963). The varieties of the crops grown were barley, Deba Abed; ley, mixture of broad red clover, Dorset Marl, and Italian ryegrass, S22; potatoes, King Edward; wheat, Champlein; kale, Thousand-headed.

Manuring. The amounts of P and K given annually were the same for each crop, 0·5 cwt P_2O_5/acre as single superphosphate and 2·0 cwt K_2O/acre as granular muriate of potash, but the amounts of N as 'Nitro-Chalk' (15·5% N 1956–67, 21% N 1968–70) differed with crop and were, in cwt N/acre:

	Barley	Ley	Potatoes	Wheat	Kale	Permanent grass
N_1	0·45	0·15	0·6	0·6	1·0	1·0
N_2	0·90	0·30	1·2	1·2	2·0	2·0

Epsom salts supplying 0·4 cwt Mg/acre was given to half of each potato plot in the seedbed and to the other half after harvest. FYM was given only to the potatoes and kale (20 tons/acre annually) and to the permanent grass (15 tons/acre annually). Calcium carbonate was applied each five years at 30 cwt/acre (in January 1966, and again in November 1970) to maintain the pH of the soils in the arable rotation at or near 7·0; the permanent grass was given 30 cwt/acre in November 1970 only.

Yields

Relative yields of the different crops, 1966–70. Appendix Table 1 shows yields of each crop as dry matter so that they may be compared directly. Without fertilisers or FYM,

TABLE 1

Responses to N, P and K fertilisers, 1966–70

	Yields (cwt/acre) of dry matter without fertiliser or FYM	Increases in the yield (cwt/acre) of dry matter from					
		N_1PK (N_1PK-O)	N_1 (N_1PK-PK)	P (N_1PK-N_1K)	K (NP_1K-N_1P)	N_2-N_1 (N_2PK-N_1PK)	N_2-N_1* (DN_2PK-DN_1PK)
Wheat grain	25·0	15·1	8·7	6·0	20·4	1·5	−0·6
Wheat straw	29·6	28·5	14·0	13·2	27·6	3·1	1·5
Barley grain	21·3	16·7	10·7	10·8	11·2	3·5	1·7
Barley straw	18·1	15·1	11·2	9·1	9·4	5·3	3·6
Potato tubers	16·8	70·0	9·1	13·1	71·8	11·2	10·0
Kale	36·2	41·9	25·3	45·8	5·6	18·9	8·4
Ley	44·4	41·7	−0·2	14·6	45·1	6·9	−3·2
Permanent grass	31·7	28·0	20·0	−0·4	7·5	19·1	7·9

* In presence of FYM (D)

wheat (grain plus straw) yielded most (54·6 cwt/acre) and potato tubers least (16·8 cwt/acre). With N_2PK, wheat still yielded most (102·8 cwt/acre), but potato tubers and kale then yielded only 5 and 6 cwt/acre less than wheat. With both FYM and fertilisers, however (DN_1PK and DN_2PK), potato tubers yielded the most dry matter; with DN_2PK they produced more than 6 tons/acre, whilst wheat and kale produced about 5·5 tons, and barley less than 4·5 tons/acre.

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Simple comparison of FYM with fertilisers, 1966–70. Appendix Table 1 shows that potatoes yielded more with 20 tons/acre of fresh FYM (D) than with N_1PK, and little less than with N_2PK. By contrast, kale yielded less with FYM than with N_1PK and much less (26 cwt/acre dry matter) than with N_2PK. Potatoes responded well to K manuring, but kale did not, so the K-rich FYM used in the experiment suited the potatoes better. Yields of wheat after potatoes and of barley after kale were much smaller with one-year-old FYM residues than with N_1PK; however, yields of the ley were as good with two-year-old FYM residues as with N_2PK because the K-responsive clover in the ley benefited from the extra K in the FYM residues and because the ley responded little to N. Fifteen tons/acre of FYM spread over the permanent grass increased yields more than N_1PK did, but much less than N_2PK, so that the N in the FYM was less effective than the fertiliser-N (15 tons of FYM had as much N as the N_2PK dressing).

Responses to N, P and K, 1966–70. Table 1 shows that N_1PK increased the yield of potatoes five-fold, more than doubled the yield of kale and almost doubled the yields of the ley and permanent grass. Yields of barley and wheat grain were increased by only three-quarters and three-fifths respectively, but straw yields were almost doubled.

Response to N. Table 1 shows that although N_1 increased the yield of kale most (25·3 cwt/acre dry matter), it also greatly increased yields of barley, wheat and permanent grass. The yield of dry potato tubers was increased little (only 9 cwt) and the ley not at all. N_2 greatly increased yields of kale and permanent grass above those with N_1 (almost by one ton/acre of dry matter), but not those of wheat and barley. N_2 increased yields of potatoes almost as much with FYM as without, showing that, without FYM, lack of K was more limiting than lack of N. With FYM, the second increment of N decreased yields of wheat grain and of the ley.

Response to P. Table 1 also shows that kale easily responded most to P (45·8 cwt/acre), whilst the yield of potato tubers was increased less than one-third as much. P also gave nearly an extra ton/acre of wheat and of barley (grain plus straw); it gave twice as much wheat straw as grain, but slightly less barley straw. P increased the yield of the ley by 14·6 cwt/acre, but decreased the yield of the permanent grass (for the third successive cycle).

Response to K. Table 1 also shows that potato tubers responded outstandingly to K (71·8 cwt/acre of dry matter); wheat (48 cwt/acre) and the ley (45 cwt/acre) were next. By contrast, barley was only half as responsive as the wheat, and the permanent grass (no clover) only one-sixth as responsive as the ley. Kale responded only a little.

Relative responsiveness to N, P and K, 1956–70. The lower half of Appendix Table 1 shows mean yields of each crop during 1956–70. Fig. 1 shows how well kale and barley responded to P comparing the O, N_1, K, N_1K and the P, N_1P, PK, N_1PK plot yields. P was most effective when N and K also were given. Both crops responded to N_2, without and with FYM. Fig. 2 similarly illustrates how potatoes, wheat and the ley, the three crops that needed K most, responded to it, and how they benefited most when N and P also were given. It also shows that without and with FYM, N_2 apparently was not enough for the potatoes, but that N_1 was enough for the wheat and the ley.

Main effects and interactions of N, P and K fertilisers, 1966–70. Table 2 shows the main effects and interactions of N, P and K calculated from the mean yields of each crop in the third cycle of the rotation. The effect of N was always positive, and although highly

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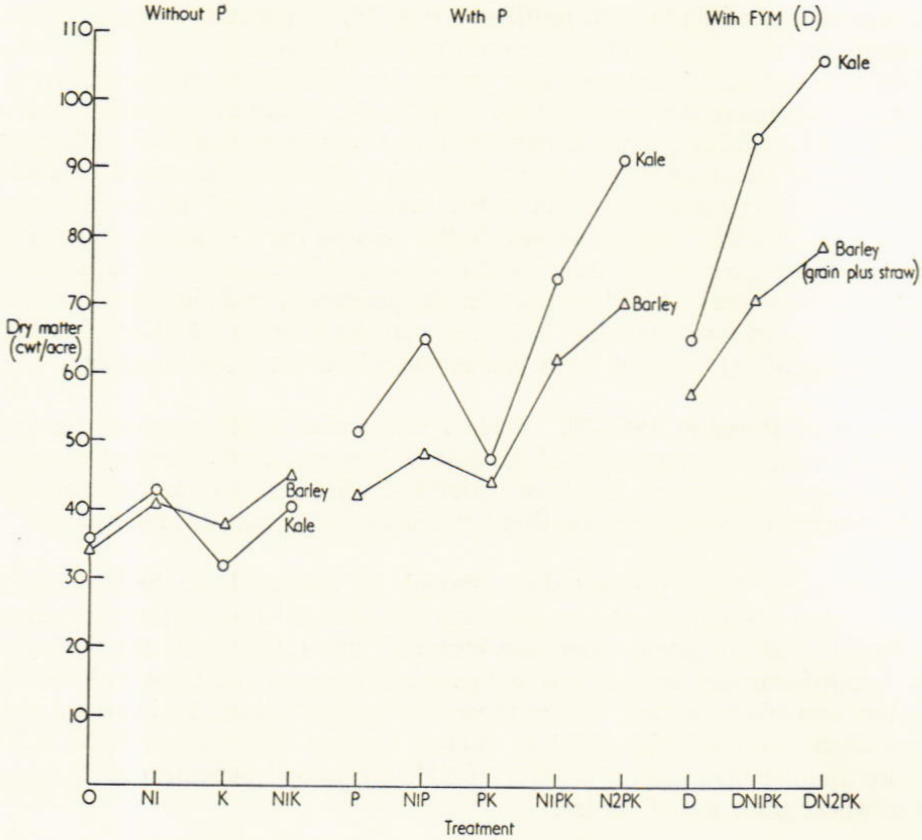

FIG. 1. The effects of N, P and K fertilisers and of FYM (D) on the yields of the two arable crops (kale and barley) that responded most to P, in the Rothamsted Reference experiment, 1956–70.

significant (1% level) on wheat straw, barley grain and straw and kale, was large only on kale. The effect of P was always positive, highly significant on all crops except wheat grain and ley, and its effect on kale was outstanding. K slightly decreased the yield of kale, but its effects on the other crops were all positive and highly significant; its effect was exceptionally large on potatoes (57·1 cwt/acre dry matter).

The NP interaction, though large and highly significant for kale, was small and often negative on the other crops. The NK interaction was always positive and was largest on potatoes, and was highly significant also for wheat and barley. The PK interaction also was always positive and was highly significant on both the wheat and the ley and significant also on barley grain and potatoes. The NPK interaction was positive except for the ley and was largest on the wheat. It was larger than the NP interaction on all crops except kale, but smaller than the other two factor interactions, confirming the great need of K by all the crops except the kale.

Main effects of N, P and K in each cycle of the rotation. Table 3 compares the main effects of N, P and K fertilisers on the five arable crops in each cycle of the rotation. The effect of N on wheat was small at first (3·7 cwt/acre dry matter), but more than doubled during the second and third cycles, when yields without N became smaller. The smaller effect of N on yields of barley and of wheat during the third cycle of the experiment cannot be explained, though we changed varieties of both (Champlein replaced Cappelle wheat and Deba Abed replaced Proctor barley). The effect of N on potatoes remained

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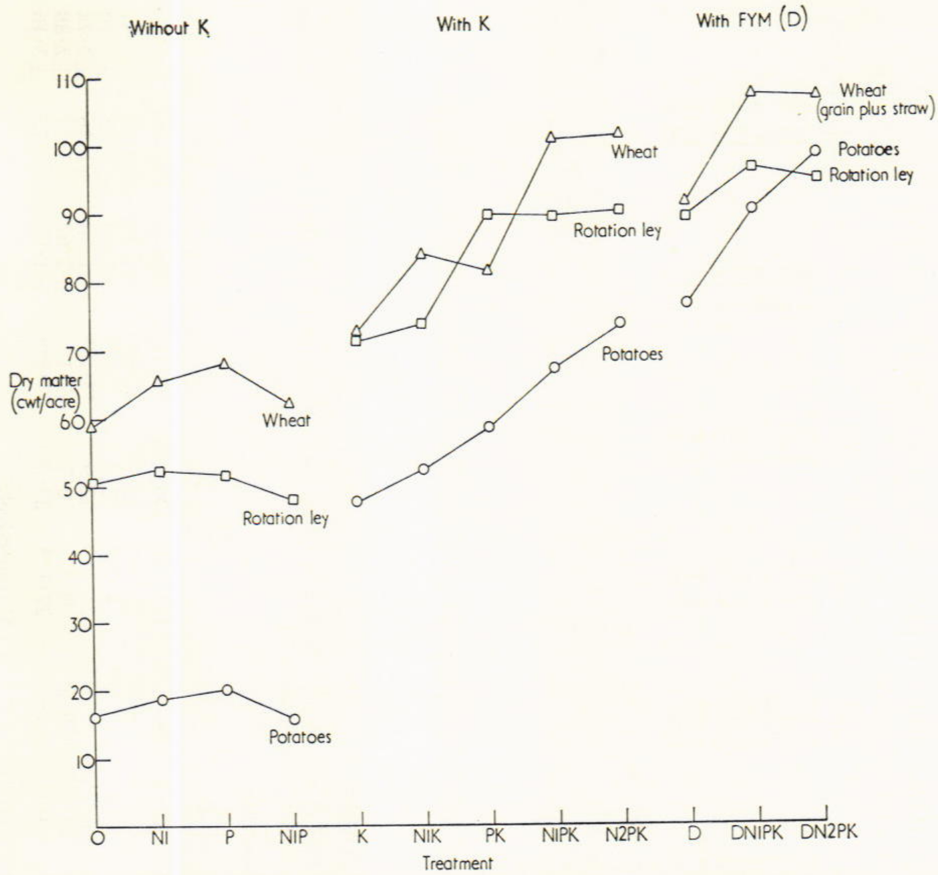

FIG. 2. The effects of N, P and K fertilisers and of FYM (D) on the yields of the three arable crops (wheat, potatoes and grass–clover ley) that responded most to K, in the Rothamsted Reference experiment, 1956–70.

small (they followed the grass–clover ley). The consistently large effect on kale became less, not more, with time. The mean effects of N on all crops during the first, second and third cycles were respectively 6·2, 7·6 and 6·8 cwt/acre.

The effect of P was large on all crops, always more in the second cycle than in the first. On potatoes and kale it was even more in the third. Its effect on kale was exceptional and trebled between the first and third cycles. Mean effects on all crops during the three cycles were respectively 7·4, 12·4 and 12·4 cwt/acre.

K had an outstanding effect on three crops, wheat, potatoes and the ley. That on wheat (about 20 cwt/acre) fluctuated only slightly between cycles, but the effect of K on potatoes more than doubled in the 15 years (from 25·4 to 57·1 cwt/acre) and became larger also on the ley. K was important for barley during the first and third cycles but, oddly, much less so in the second. K negligibly affected kale yields. Mean effects on all crops during the three cycles were respectively 16·3, 16·9 and 23·7 cwt/acre.

Responses to FYM. Table 4 shows the responses (dry matter) of potatoes and kale to 20 tons/acre and of permanent grass to 15 tons/acre of FYM (D) and of wheat, barley and the ley to FYM residues during the third cycle of the rotation. Without NPK, FYM enormously increased the yield of potato tubers and greatly increased the yields of kale and of permanent grass. One-year-old residues also greatly increased yields of wheat and barley. Two-year-old FYM residues increased the yield of the clover-rich ley

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TABLE 2

Main effects and interactions of N, P and K fertilisers on five arable crops grown from 1966 to 1970

		Dry matter (cwt/acre)								Coefficient of variation (%)
		N	P	K	NP	NK	PK	NPK	S.E.	
Wheat	grain	2·0	1·1	9·0**	−1·4	5·2**	3·3**	3·0**	±1·00	10·9
	straw	5·6**	5·5**	13·5**	−0·9	5·5**	4·7**	4·0*	±1·52	12·3
Barley	grain	5·0**	5·7**	3·9**	0·7	2·9**	2·2*	2·1*	±0·90	10·6
	straw	5·6**	4·8**	3·5**	1·4	3·0**	1·7	1·2	±0·86	12·0
Potato tubers		2·8	7·7**	57·1**	−2·6	6·6*	5·7*	2·5	±2·74	18·4
Kale		11·5**	29·6**	−2·1	9·7**	1·1	3·6	2·9	±2·88	18·3
Ley		1·5	7·4*	33·8**	−2·4	1·6	10·6**	−0·9	±3·16	16·6

*, ** Significant at probability levels of 5% and 1%

TABLE 3

Main effects (cwt/acre of dry matter) of N, P and K on arable crops grown in each of the three cycles, 1956–60, 1961–65 and 1966–70

	Main effect of N			Main effect of P			Main effect of K			S.E.		
	1956–60	1961–65	1966–70	1956–60	1961–65	1966–70	1956–60	1961–65	1966–70	1956–60	1961–65	1966–70
Wheat (grain + straw)	3·7	11·8**	7·6**	6·9**	9·7**	6·6*	20·2**	19·9**	22·4**	±1·94	±2·58	±2·41
Barley (grain + straw)	7·3**	11·0**	10·5**	8·0**	10·8**	10·5**	8·2**	2·2	7·4**	±2·09	±2·15	±1·70
Potato tubers	3·3	2·3	2·8	5·4**	6·7**	7·7**	25·4**	32·9**	57·1**	±1·70	±1·36	±2·74
Kale	16·9**	13·6**	11·5**	10·8**	25·6**	29·6**	0·8	0·7	−2·1	±2·67	±3·35	±2·88
Ley	−0·1	−0·8	1·5	6·1**	9·0**	7·4*	27·1**	29·0**	33·8**	±1·68	±2·75	±3·16

*, ** Significant at probability levels of 5% and 1% respectively

more than fresh FYM increased the yield of permanent grass. Tables 1 and 4 show that fertiliser K increased yields of potatoes and the ley almost as much as the FYM did, so presumably it was the K in the FYM that made it so beneficial to these crops.

TABLE 4

Mean increases in yield (cwt/acre) of dry matter from FYM (D) tested with and without NPK fertilisers, 1966–70

	Without NPK fertiliser (D-O)	With NPK fertiliser: N at single rate (DN_1PK-N_1PK)	With NPK fertiliser: N at double rate (DN_2PK-N_2PK)
Direct effects			
Potato tubers	78·7	25·6	24·4
Kale	34·5	25·3	14·8
Permanent grass	32·7	24·4	13·2
Residual effects			
Wheat grain	11·7	2·6	0·5
Wheat straw	19·9	7·7	6·1
Barley grain	12·5	4·7	2·9
Barley straw	10·7	7·7	6·0
Ley	48·2	9·2	−0·9

Table 4 also shows that although the response to FYM was much less when fertilisers also were given, that of potatoes was as large with N_2 as with N_1, showing again that the K in the FYM was benefiting this K-responsive crop. With kale and permanent grass, however, N_2 halved the response to FYM, showing that the yields of these crops were limited more by the supply of N than K. Yields of wheat and barley were increased by one-year-old FYM residues, but less with fertilisers than alone; grain yields, especially, were less with N_2 than with N_1. N_2 eliminated the response by the ley to two-year-old residues, showing that then neither N nor K was lacking.

TABLE 5

Mean yields (tons/acre) of potato tubers and of kale without and with FYM, 1956–70

Fertilisers	Potato tubers: 0	Potato tubers: 19	Kale: 0	Kale: 19
	Mean amount of FYM applied (tons/acre)			
None	3·53	15·48	9·17	16·08
N_1PK	13·55	19·54	18·70	23·86
N_2PK	15·13	21·24	24·14	29·60

Table 5 shows that over the whole period of the experiment FYM alone more than quadrupled the fresh yield of potatoes and increased by more than two-thirds the fresh yield of kale, but that fertilisers (N_2PK) and FYM together increased the yield of potatoes six-fold and more than trebled that of kale, so the combination of the two gave by far the largest yields of both crops.

Response to Mg, 1967–70. Mg consistently increased the yield of potatoes only where no other nutrient was applied; otherwise responses were erratic and inconsistent. Averaged over all main treatments Mg did not affect yields.

Growth of crops and nutrient deficiency symptoms, 1956–70. The soil contained little soluble P or K when the experiment started (Williams, Cooke & Widdowson, 1963)

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and so symptoms of deficiencies of these nutrients soon showed in responsive crops. The kale always responded dramatically to P, especially in the seedling stage, but differences in height at harvest (late October) between kale manured and unmanured with P became larger with time. The leaves of wheat and barley grown without P often turned purple in spring though they recovered later, but neither crop grew well without it.

The leaves of potatoes not given K showed typical K-deficiency symptoms and the haulms died by late July. Haulms growing on other plots remained green until early September. The clover in the ley was also very sensitive to K and without K fertiliser its leaves often showed the marginal leaf scorch typical of K deficiency and the plants often died subsequently. With K, clover dominated the sward, except when N_2 also was given, then the ryegrass dominated. The leaf tips of young barley not given K became white soon after emergence each spring, but the symptoms disappeared in about three weeks, though growth was still restricted. Although the leaves of wheat showed K-deficiency less frequently than barley did, it grew badly without K and its stems were weak and straggly at harvest.

Symptoms of N deficiency were less obvious than of P or K, but without N kale leaves frequently became purple and then yellow in autumn. N increased the proportion of ryegrass to clover in the ley and soon made the tall grasses, cocksfoot, timothy and meadow foxtail dominant in the permanent grass; without K, the permanent grass consisted of short fine-leaved fescues and meadow grasses.

Discussion

Table 6 compares the mean yields of the five arable crops grown with all combinations of N, P and K in each cycle of the rotation. Without N, yields of both wheat grain and straw, particularly straw, were largest during the first cycle and smallest during the third, but with N, varied little, suggesting that mean yields declined because wheat obtained less N from the soil with time. Table 11 confirms this. There is no obvious reason why barley yielded less during the second cycle than in the first (Proctor was grown in both). Like wheat, barley needed N to yield well, but yields both without and with N were smaller during the second cycle. The larger mean yield during the third cycle was because Deba Abed was grown instead of Proctor.

TABLE 6

Mean yields (cwt/acre of dry matter) of five arable crops grown in rotation with all combinations of N, P and K fertilisers in each cycle of the experiment

	1956–60	1961–65	1966–70
Wheat (grain + straw)	79·8	74·1	68·3
Barley (grain + straw)	44·8	38·7	49·3
Potato tubers	29·9	33·8	47·0
Kale	49·2	46·7	49·9
Ley	60·2	77·1	60·0

Potatoes (always King Edward) responded exceptionally well to K and the mean yields increased more than one and a half times from the first to the third cycles because yields with K increased by the same ratio. Yields without K were practically identical in all three cycles, but Table 7 shows that the amount of fertiliser K supplied to the crops increased with time, so evidently the potatoes made full use of this extra K. Mean yields of kale varied little with time.

Mean yields of the ley were larger during the second than the first cycle, because we changed from a pure clover sward in 1956 and 1957 to a ryegrass–clover sward afterwards. They declined during the third cycle mainly because yields in 1970 were only

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one-half to two-thirds of those during 1966–69. The grass and clover established badly in 1970 and we obtained only three cuts instead of the usual four.

N, P and K contents of the crops and manures

N, P and K given during 1956–70

Fertilisers. The amounts of N (as a granular ammonium nitrate-calcium carbonate mixture containing either 15·5 or 21% N), of P (as granular single superphosphate) and of K (as sulphate of potash until 1966 and then muriate of potash) applied to individual crops each year are in Table 7.

TABLE 7

Amounts (lb/acre) of nitrogen, phosphorus and potassium supplied annually by fertilisers to crops grown in rotation and to permanent grass at Rothamsted, 1956–70

	Nitrogen 1956–70		Phosphorus 1956–70	Potassium		
	N_1	N_2		1956–60	1961–65	1966–70
Wheat	67	134	24·4	93	139	186
Barley	50	101			93	
Potatoes	67	134			232	
Kale	112	224			93	
Ley	17	34			186	
Total in five years	314	627	122·0	465	743	930
Permanent grass	112	224	24·4	93	232	186

Farmyard manure (FYM). Initially FYM was applied at 15 tons/acre to each crop in the rotation each year. From 1959 this was changed, because the wheat and barley became badly lodged where FYM had been given, and so 20 tons/acre of FYM was applied only for potatoes and kale. The permanent grass was given 15 tons/acre annually. The N, P and K contents of the batches of FYM used from 1956 to 1960 have already been given (Williams, Cooke & Widdowson, 1963). Table 8 shows the N, P and K contents of the FYM used since then and Table 9 the amounts of N, P and K added in the 20-ton dressings. These varied greatly from year to year, but the table shows that the batches used in the third cycle of the experiment (1966–70) supplied the same amount of N, but more P and K, than those used in the second. The analyses show that the four dressings of FYM given in ten years supplied slightly more P, but slightly less K than was added in the ten annual dressings of P and K (244 lb P and 1673 lb K in ten years). Table 10 shows the total amounts of N, P and K added by the dressings in each cycle of

TABLE 8

Chemical analyses of FYM, 1961–70

Cropping year	% dry matter	% in dry matter of N	P	K
1961	26·81	1·99	0·67	2·49
1962	24·50	2·40	0·31	2·22
1963	29·65	2·92	0·41	2·34
1964	18·37	3·24	0·65	3·48
1965	25·75	2·81	0·48	3·96
1966	22·50	2·99	0·72	4·32
1967	26·97	2·84	0·64	4·64
1968	22·80	2·29	0·55	4·30
1969	21·90	2·83	0·94	4·64
1970	26·30	2·97	0·78	4·26

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TABLE 9

Annual amounts (lb/acre) of nitrogen, phosphorus and potassium supplied by 20 tons/acre of FYM, 1961–70

Cropping year	N	P	K
1961	239	80	299
1962	263	34	244
1963	388	54	311
1964	267	53	286
1965	324	55	457
Mean 1961–65	296	55	319
1966	301	73	436
1967	343	77	561
1968	234	56	439
1969	278	92	455
1970	350	92	502
Mean 1966–70	301	78	479
Mean 1961–70	299	67	399

TABLE 10

Total amounts (lb/acre) of nitrogen, phosphorus and potassium supplied by FYM in each five-year cycle of the experiment

Years	N	P	K
1956–60	849	158	1120
1961–65	592	110	639
1966–70	602	156	957

the experiment. Most was added in the first cycle because all crops were given FYM from 1956–58 and more in the third cycle than in the second because the batches of FYM contained more.

Chemical analyses of the crops

Nitrogen was determined after Kjeldahl digestion using $CuSO_4$ and K_2SO_4 as catalysts by 'Technicon AutoAnalyzer' using Varley's (1966) method modified by adding citrate tartrate buffer.

Phosphorus by 'Technicon AutoAnalyzer' using the method of Fogg and Wilkinson (1958) after ashing with magnesium acetate and solution in dilute HCl.

Potassium by 'EEL' flame photometer after dry ashing and solution in dilute HCl.

N, P and K removed by individual crops during 1956–70. Appendix Table 2 shows the large differences in the amounts of N, P and K removed both within the range of fertiliser and FYM dressings tested and between the crops themselves. These are the best estimates that we have of the absolute amounts of N, P and K removed by each crop.

Mean annual amounts of N, P and K removed by all crops from the soil during 1956–70. Fig. 3 shows that the annual amounts of N, P and K removed from the soil followed no consistent pattern. The amount of each element is the mean of uptakes from all crops not given that element. N and K uptakes increased from 1956 to 1958, but then tended to diminish, though peaks for N occurred in 1967 and for K in 1969. Climatic variations from year to year do not explain these changes in uptakes. The amount of P supplied by the soil also tended to diminish slowly with time, but it varied less from year to year than that of N and K.

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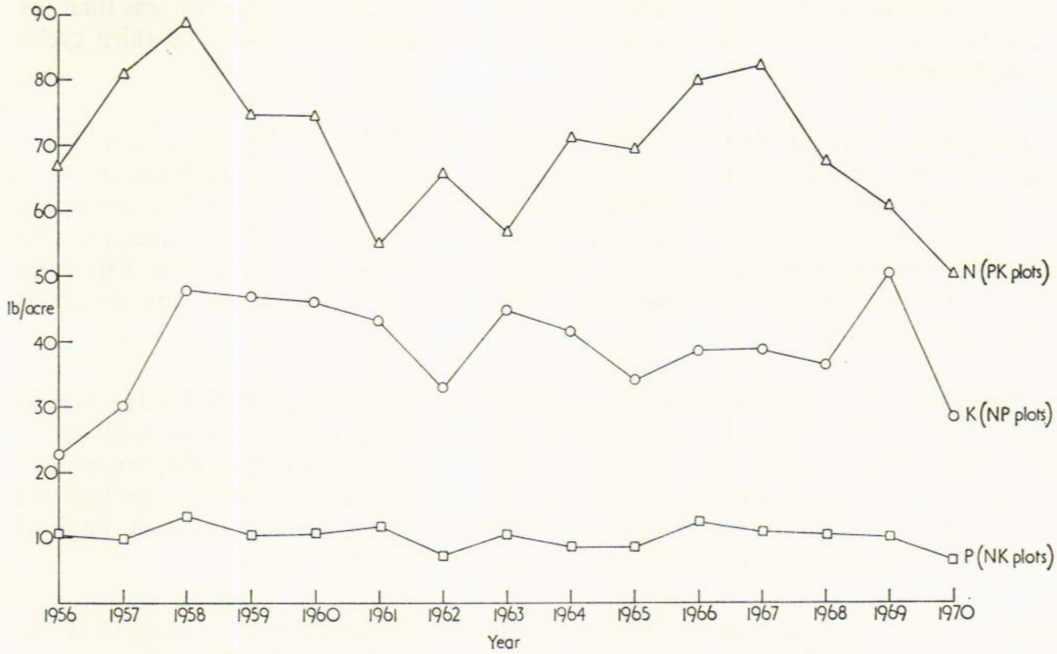

FIG. 3. The mean annual amounts (lb/acre) of N, P and K taken from the soil by the five arable crops grown on the Rothamsted Reference plots from 1956–70. Mean of five crops for P and K, mean of four (excluding ley) for N.

Mean annual amounts of N, P and K removed by individual crops from the soil during 1956–70. Table 11 shows the amounts of N removed by crops given P and K, of P by crops given N and K and of K by crops given N and P fertilisers each five years.

TABLE 11

Mean annual amounts (lb/acre) of nitrogen, phosphorus and potassium removed from the soil by each crop in each five-year cycle of the experiment

	N (from PK plots)			P (from NK plots)			K (from NP plots)		
	1956–60	1961–65	1966–70	1956–60	1961–65	1966–70	1956–60	1961–65	1966–70
Wheat grain	77	62	59	12	12	11	14	15	10
Wheat straw	22	18	18	2	2	2	19	16	8
Barley grain	38	30	39	7	5	8	12	13	15
Barley straw	19	8	8	2	0·6	1	13	10	10
Potato tubers	80	78	84	6	6	11	20	18	19
Kale	73	60	66	11	6	4	70	66	72
Ley	226	297	239	14	15	13	45	60	58
Total in five years	309*	256*	274*	54	46·6	50	193	198	193
Permanent grass	114	74	76	17	13	11	42	38	43

* Total of four years for N (excluding the ley, which contained clover)

Nitrogen. The herbage from the clover-rich leys removed more than 200 lb N/acre per annum in each cropping cycle, almost as much N as the other four crops obtained altogether, even though some of the N recovered by the potatoes must have derived from the N-rich clover roots that were dug down before them. So, the best estimate of the nitrogen-supplying capacity of this soil probably was given by the wheat, kale and barley, which together obtained 184 lb N/acre from this soil. So 61 lb N/acre per year is

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our best estimate of the N provided by this soil, which was about one-fifth less than the 75 lb N/acre per year obtained by the permanent grass in the second and third cycles of the experiment.

Phosphorus. Wheat obtained more P from this soil than barley did, but no more than the grass–clover ley or the permanent grass. Kale yields were small unless P was given, a fact supported by the decreasing amounts of P that it obtained from the soil in each succeeding crop cycle. By contrast the potatoes obtained more P with time, presumably reflecting the larger yields from the larger dressings of K given in the second and then again in the third cycle of the experiment (Table 7). On average, this soil supplied about 10 lb P/acre per year.

Potassium. Potatoes obtained least K from this soil and kale most (Table 11); potato yields were increased greatly by fertiliser K, but kale yields, little (Table 1). Both barley and wheat obtained less K from this soil than the ley or permanent grass did, presumably because the latter were harvested green whereas the cereals were mature and had lost most of the K contained in their leaves. On average, the five arable crops each obtained about 40 lb K/acre per year, almost the same as the permanent grass.

Recovery of N, P and K from the fertilisers by all crops during 1961–70. Table 12 shows the apparent recoveries by the crops of the N, P and K given as fertilisers. The amount of each nutrient in crops grown without it, but given the other two nutrients, was sub-

TABLE 12

Apparent annual recoveries of nitrogen, phosphorus and potassium given as fertiliser from 1961–65 and from 1966–70

	Recovery of N from N_1 (N_1PK-PK)				Recovery of N from N_2 (N_2PK-PK)			
	1961–65		1966–70		1961–65		1966–70	
	lb/acre	% recovery	lb/acre	% recovery	lb/acre	% recovery	lb/acre	% recovery
Wheat grain	30	64	19	35	42	52	39	43
Wheat straw	13		4		28		18	
Barley grain	16	44	16	43	29	38	32	43
Barley straw	6		5		10		11	
Potato tubers	34	50	24	36	42	31	57	43
Kale	50	44	37	33	108	48	71	32
Mean	—	50	—	37	—	42	—	40
Permanent grass	52	47	46	41	127	57	107	48

	Recovery of P (N_1PK-N_1K)				Recovery of K (N_1PK-N_1P)			
	1961–65		1966–70		1961–65		1966–70	
	lb/acre	% recovery	lb/acre	% recovery	lb/acre	% recovery	lb/acre	% recovery
Wheat grain	5·1	27	4·9	30	7	38	10	33
Wheat straw	1·5		2·5		46		52	
Barley grain	4·4	22	5·9	27	3	25	8	26
Barley straw	0·9		0·7		20		41	
Potato tubers	5·7	23	7·2	30	89	38	140	75
Kale	10·4	43	12·2	50	78	84	96	52
Ley	12·1	49	9·0	37	176	95	166	89
Mean	—	33	—	35	—	56	—	55
Permanent grass	4·3	18	6·6	27	122	53	131	70

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tracted from the amount in crops given all three. The results are expressed in absolute amounts and as percentages of that given as fertiliser.

Nitrogen. Because different amounts of N were given for each crop (Table 7) comparisons of percentage recoveries are more relevant than of absolute amounts. The results from 1956–60 have already been published (Williams, Cooke & Widdowson, 1963), so Table 12 shows only that the crops recovered more N in the second than in the third cycle. There was no consistent difference between the abilities of the different crops to recover N. Permanent grass was no more efficient than wheat with N_1, though slightly more so with N_2.

Phosphorus. Although giving P increased yields of kale more than those of any of the other crops, the kale recovered less P during 1961–65 than the ley, which responded little. On average only one-third of the P given was recovered by the crops, the balance presumably remaining as recoverable P residues.

Potassium. The clover-rich ley apparently recovered more K than any other crop, perhaps because a cut was taken in the seeding year (except 1970). Potatoes and permanent grass recovered about three-quarters of the K given for them during the third cycle, but much less during the second; the cereals recovered only a quarter to a third and most of that was in the straw. On average 55% of the K applied during the rotation was recovered by the five crops, more even than that of N, which usually is considered to be the most important nutrient. The uptake results clearly show that lack of K limited yield more than N did. Table 3 confirms that this was so.

Recovery of N, P and K from farmyard manure during 1961–70. Table 13 shows the apparent recoveries of N, P and K from FYM. The amounts in completely unmanured

TABLE 13

The apparent annual recoveries of nitrogen, phosphorus and potassium from FYM (D) applied without and with fertilisers from 1961–65 and from 1966–70

	Without fertiliser (D-O)				With single amount of fertiliser-N (DN_1PK-N_1PK)				With double amount of fertiliser-N (DN_2PK-N_2PK)			
	1961–65		1966–70		1961–65		1966–70		1961–65		1966–70	
	lb/ acre	% recovery	lb/ acre	% recovery	lb/ acre	% recovery	lb/ acre	% recovery	lb/ acre	% recovery	lb/ acre	% recovery
						Nitrogen						
Potato tubers	71	24	79	26	20	7	38	13	42	14	20	7
Kale	35	12	28	9	42	14	28	9	49	17	32	11
Permanent grass	64	29	78	34	63	28	69	30	39	18	50	22
						Phosphorus						
Potato tubers	10	18	16	21	4	7	8	10	6	11	7	9
Kale	9	16	10	13	8	14	9	11	6	11	9	12
Permanent grass	10	24	14	24	7	17	11	18	7	17	8	14
						Potassium						
Potato tubers	110	34	185	39	69	22	118	25	80	25	124	26
Kale	93	29	99	21	91	28	67	14	77	24	96	20
Permanent grass	142	59	187	52	92	38	162	45	99	41	189	53

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crops were subtracted from those in crops given FYM only (D-O), and the amounts in those given fertilisers only from those in crops given both fertilisers and FYM (DN_1PK-N_1PK and DN_2PK-N_2PK). These calculations are subject to some error, because the interactions of any two nutrients in FYM on the recovery of the third are ignored.

Nitrogen. The potatoes recovered only one-quarter of the N in the FYM and the kale one-tenth. The permanent grass recovered more (about one-third of that given), perhaps because this FYM was applied in spring and so there was less opportunity for the N in it to be leached. Giving NPK fertiliser with FYM diminished the amounts of N recovered from it by potatoes and by grass, but not by kale, which recovered more.

Phosphorus. The FYM supplied far more P than we gave as superphosphate. Absolute recoveries were larger than those from fertiliser, and percentage recoveries smaller (about one-fifth of that given). In direct contrast, potatoes at Woburn recovered the P in FYM three times as efficiently as the P given as superphosphate. Permanent grass recovered P more efficiently, from a smaller dressing of FYM, than the root crops did, and giving NPK fertiliser diminished its recovery.

Potassium. Potatoes and kale recovered large amounts of the K in FYM given alone (potatoes then recovered almost one-third of it) and when NPK fertilisers also were given. Permanent grass recovered more than half of the K in FYM given alone and only a little less with NPK fertilisers.

The apparent effective contribution of the N, P and K in the batches of FYM used from 1961 to 1970 for potatoes and kale was (in lb/acre): 40 of N, 9 of P and 100 of K (when averaged over the six available contrasts for each crop). If we accept the fertiliser efficiencies shown in Table 12 (i.e. 40% for N, 33% for P and 55% for K), these recoveries from the FYM were equivalent to giving fertilisers supplying (in lb/acre) 100 of N, 27 of P and 180 of K. The N, P and K in the FYM given for permanent grass was recovered more efficiently than that given for the root crops, presumably because its roots explored more soil.

Amounts of N, P and K added to and removed from the soil in 15 years (1956–70). Appendix Table 3 shows that the crops removed less N in the third than in the first or second cycles of the experiment whether or not fertiliser N or FYM was given, confirming that this soil's ability to supply nitrogen was diminishing with time. By contrast, the amounts of P and K removed by crops not manured with P or K changed little with time, though when both P and K were given, the crops removed more in the second than in the first cycle of the experiment and still more in the third. This happened whether or not FYM was also given and presumably reflects the recovery by the crops of the residues from earlier dressings.

Nitrogen. Table 14 shows that, averaged over the three cycles, the five crops together removed from 350 to 850 lb N/acre. The grass–clover ley contained 130 to 250 lb N/acre in its herbage (Appendix Table 2) of which 70 to 190 lb N/acre was contributed by the clover. So, deducting this N from the total, the largest amount of N removed from the soil in five years was probably about 350 lb N/acre (obtained by deducting 190 from the total amount of N removed on the PK plots) and the largest addition about 800 lb/acre (obtained by deducting 70 from the total amount of N removed on the DN_2PK plots) Even after allowing for the N contributed by the clover, N was only gained if FYM was given twice in the rotation.

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TABLE 14

The mean amounts (lb/acre) of nitrogen, phosphorus (P) and potassium (K) applied for, and removed by, five crops grown in three five-year cycles of the experiment, from 1956–70

	Treatments											
	O	N_1	P	N_1P	K	N_1K	PK	N_1PK	N_2PK	D	DN_1PK	DN_2PK
						Nitrogen						
Added	0	314	0	314	0	314	0	314	627	681	995	1308
Removed	344	409	366	403	438	537	533	634	733	607	750	848
Difference	−344	−95	−366	−89	−438	−223	−533	−320	−106	+74	+245	+460
						Phosphorus						
Added	0	0	122	122	0	0	122	122	122	141	263	263
Removed	38	42	58	56	48	50	73	85	89	82	106	110
Difference	−38	−42	+64	+66	−48	−50	+49	+37	+33	+59	+157	+153
						Potassium						
Added	0	0	0	0	713	713	713	713	713	905	1618	1618
Removed	181	205	221	195	416	453	511	584	634	630	896	969
Difference	−181	−205	−221	−195	+297	+260	+202	+129	+79	+275	+722	+649

Phosphorus. Table 14 also shows that the amount of P added in superphosphate (122 lb P/acre) exceeded the most removed by the crops. Thus, with most fertiliser (N_2PK), almost one-quarter of the P given remained as a residue and, when FYM was given too, three-fifths of the P given was unused. If we subtract the 50 lb P/acre obtained by the crops given only N and K fertiliser (i.e. the P provided by the soil in five years) from the 110 lb P/acre removed by the crops given the largest manuring (DN_2PK), we see that the largest yields apparently recovered only 60 lb P/acre (i.e. 12 lb P/acre annually).

Potassium. Table 14 also shows that the crops not given K removed about 200 lb K/acre in five years, whilst those given most fertiliser (N_2PK) removed 630 lb K/acre and those given FYM also, 970 lb K/acre. The amount of fertiliser K given (713 lb/acre in five years) was more than sufficient to balance the K removed by the crops grown with fertilisers alone. The larger yields, especially of potatoes, from the FYM and fertiliser treatments (Table 5) suggest that the extra K added in the FYM (905 lb K/acre in five years) increased not only the K contents, but also the yields of the crops most responsive to K. The fact that the largest yields removed 970 lb K/acre in five years, and that the crops given N and P alone obtained almost 200 lb K/acre from the soil in five years shows that these crops recovered 770 lb K/acre (154 lb K/annum) from the fertilisers and FYM given for them. If all of this K was needed by these crops, then by using the recovery factors of 55% for fertiliser K (Table 12) we can see that 280 lb of fertiliser K was apparently needed each year by these crops.

Discussion

The results presented here allowed us to measure not only the supply of N, P and K from reserves in the soil, but also the recovery of N, P and K added as fertilisers and as FYM over a period of 15 years. The crops grown differed enormously in their abilities to obtain P and K from the soil. Wheat, for example, obtained more than twice as much P, but less than half as much K as the kale did that followed it. The yields of wheat were increased mainly by giving K, those of kale mainly by giving P.

The results also show that some crops recovered the N, P and K given for them more efficiently than others. For example, wheat usually recovered a larger percentage of

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fertiliser N than kale did, although kale yields were increased far more by the N than those of wheat. Kale recovered fertiliser K very efficiently, whilst responding very little to it.

The N, P and K contained in the FYM was recovered less efficiently than that given as fertiliser. For example, no more than 25% of the N in the FYM (it was dug down in the autumn) and less than 20% of the P and 40% of the K was recovered by the potatoes and kale, though the permanent grass used the K in FYM almost as efficiently as that in fertiliser. However, although giving fertiliser as well as FYM usually diminished the recovery of the N, P and K in the FYM, this did not always happen, for kale recovered more of the N in the FYM (from roughly 30 to 45 lb/acre) and only a little less of the K with fertiliser than without.

The balance sheets for N, P and K showed that when fertilisers were given alone (N_2PK) the crops removed more N than was added (after allowing for the N contributed by the clover). Hence soil nitrogen reserves must have been considerably depleted. By contrast, when FYM as well as fertiliser was given to the potatoes and kale, more N was added than was removed (460 lb N/acre in each five-year cycle), increasing the nitrogen content of this soil (Williams, 1973). Also, when fertilisers were used alone (N_2PK), they did little to enhance the P and K reserves in the soil; only 33 lb of P and 79 lb of K of that given remained at the end of each five-year cycle, assuming that none of this fertiliser K was lost by leaching during winter. However, where FYM also was given, both the P and the K residues in the soil were enormously increased. Notice that both the response to K, and the yield of potatoes increased in each cycle of the experiment (Tables 3 and 6).

Summary

Yields. An experiment begun in 1956 to measure the effects of FYM (D) and N, P and K fertilisers on a five-course rotation of winter wheat, kale, spring barley, one-year ley and potatoes, grown on very small plots (0·00128 acre) completed its third cycle in 1970. From 1957 a strip of permanent grass was given the same range of FYM and fertiliser treatments. Mg was tested on the potatoes from 1968.

N greatly increased the yields of all crops except the ley, and P of all crops except the permanent grass. Kale and wheat were the most responsive to N and kale easily the most responsive to P. K increased the yields of potatoes exceptionally and of wheat and the ley greatly; barley and the grass responded less and the kale negligibly.

The main effect of P on kale trebled, and of K on potatoes more than doubled, between the first and third cycles. Averaged over all five arable crops during the first, second and third cycles of the rotation mean 'effects' (in cwt dry matter/acre) were respectively 6·2, 7·6 and 6·8 for N, 7·4, 12·4 and 12·4 for P, and 16·3, 16·9 and 23·7 for K. So, K was easily the most important nutrient for these crops on this soil.

Fresh dressings of FYM greatly increased yields of potatoes and kale. Without fertilisers, the ley benefited more from two-year-old residues of 20 tons/acre of FYM, than wheat and barley did from one-year-old residues, and more than permanent grass did from fresh dressings of 15 tons/acre. FYM alone (D) was as effective as N_2PK for potatoes and the ley and as effective as N_1PK for the permanent grass, but less good than N_1PK for the kale. Applying NPK fertilisers decreased benefits from FYM, but a combination of both gave the largest yields of each crop. Mg increased the yield of potatoes a little only where no other nutrient was applied. On average it did not affect yields. The mean yield of wheat (from all combinations of N, P and K) decreased with time and was 10% smaller during the third than the first cycle, but the mean yield of potatoes increased with time and was 60% larger. The mean yields of kale, barley and the ley changed little with time.

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N, P and K. From 1956 to 1970 we measured the input of N, P and K (in fertilisers and in FYM) and the recovery of N, P and K by five arable crops, and, from 1957 by permanent grass also. From these measurements we estimated the amounts of N, P and K removed by each crop from the soil alone. Mean estimates from the arable crops during 1961–70 were about 61 lb/acre of N, 10 of P and 39 of K; the permanent grass obtained 75 lb/acre N, 12 lb of P and 40 lb of K. The red clover in the ley contributed from 70–190 lb N/acre to the N in the herbage plus the unmeasured N in its roots. Actual amounts of N, P and K obtained from the soil varied greatly from year to year, but only those of N diminished consistently with time.

The percentage of the N, P and K given as fertiliser recovered by the arable crops differed, but over the 15 years 43% of the N (from N_1 and N_2), 29% of the P and 54% of the K was recovered. P was recovered more efficiently with time (from 18 to 35%), the K a little more (from 51 to 55%), but not the N.

The N, P and K in the FYM from 1961–70 (20 tons contained 299 lb N, 67 lb P and 399 lb K per acre) was recovered less completely than that in fertiliser; no more than 25% of the N, 20% of the P and 36% of the K was recovered by potatoes or by kale, and giving fertilisers with it diminished recovery further. Its mean apparent effective contribution was 40 lb/acre of N, 9 of P and 100 of K. The permanent grass recovered roughly 31% of the N, 24% of the P and 55% of the K in the FYM when given alone, but less with fertilisers.

A balance sheet for N, P and K was constructed. This showed that the largest amount of N removed by the crops from this soil in five years was about 350 lb/acre (after allowing for the N added by the clover) and the largest addition about 800 lb/acre (where FYM and fertilisers were given). The largest loss of P from the soil was about 50 lb/acre, and the largest gain about 150 lb/acre. Comparable values for K were 200 and 700 lb/acre. The crops took up from 350 to 850 lb/acre of N, from 40 to 110 of P and from 180 to 970 of K in five years.

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APPENDIX TABLE 1

Mean yields (cwt/acre of dry matter) from combinations of N, P and K fertilisers and FYM (D) tested on five arable crops and on permanent grass in the Rothamsted Reference experiment (in the third and in all three cycles)

	Treatments											
	O	N_1	P	N_1P	K	N_1K	PK	N_1PK	N_2PK	D	DN_1PK	DN_2PK
1966 to 1970												
Wheat grain	25·0	26·3	27·2	19·7	28·5	34·1	31·4	40·1	41·6	36·7	42·7	42·1
Wheat straw	29·6	34·6	35·4	30·5	36·9	44·9	44·1	58·1	61·2	49·5	65·8	67·3
Barley grain	21·3	24·8	26·1	26·8	22·2	27·2	27·3	38·0	41·5	33·8	42·7	44·4
Barley straw	18·1	20·5	21·0	23·8	18·1	24·1	22·0	33·2	38·5	28·8	40·9	44·5
Potato tubers	16·8	18·2	24·0	15·0	64·2	73·7	77·7	86·8	98·0	95·5	112·4	122·4
Kale	36·2	39·8	55·3	72·5	32·2	32·3	52·8	78·1	97·0	70·7	103·4	111·8
Ley	44·4	42·8	42·7	41·0	65·0	71·5	86·3	86·1	93·0	92·6	95·3	92·1
Permanent grass	31·7	43·6	28·6	52·2	33·5	60·1	39·7	59·7	78·8	64·4	84·1	92·0
1956 to 1970												
Wheat grain	26·3	29·0	29·3	25·0	31·1	35·7	32·9	40·7	39·5	37·6	40·4	40·1
Wheat straw	32·7	36·4	38·7	37·0	41·4	48·1	48·4	59·6	61·6	53·7	66·4	66·4
Barley grain	18·3	21·3	22·6	24·7	19·5	23·5	23·4	32·0	35·9	29·6	35·6	36·0
Barley straw	15·6	19·6	19·5	23·6	18·2	21·4	20·7	30·2	34·5	27·6	35·5	42·9
Potato tubers	16·2	18·7	20·1	15·6	47·4	52·1	58·2	66·8	73·3	76·2	90·0	98·0
Kale	35·5	42·7	51·4	65·2	31·7	40·5	47·7	74·0	91·4	65·3	94·7	106·2
Ley	50·6	52·3	51·7	48·0	71·2	73·6	89·6	89·2	89·9	89·0	96·2	94·5
Permanent grass	37·5	45·1	33·2	54·6	35·8	65·7	45·7	62·9	79·6	62·6	81·2	91·7

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APPENDIX TABLE 2

Mean annual amounts (lb/acre) of nitrogen, phosphorus (P) and potassium (K) removed by five arable crops and by permanent grass grown with combinations of N, P and K fertilisers and FYM (D) in the Rothamsted Reference experiment from 1956–70

(15 years of arable crops, 14 years of permanent grass)

	Treatments											
	O	N_1	P	N_1P	K	N_1K	PK	N_1PK	N_2PK	D	DN_1PK	DN_2PK
Nitrogen												
Wheat grain	58·2	68·1	63·6	60·2	64·1	84·6	66·0	89·7	100·8	79·3	92·1	103·4
Wheat straw	16·0	20·1	18·6	24·3	16·7	24·9	19·2	28·8	42·6	24·1	39·0	51·3
Barley grain	29·8	40·7	35·1	42·8	29·3	41·5	35·6	52·4	68·3	48·3	62·5	73·4
Barley straw	9·3	14·8	9·6	15·7	12·4	14·4	11·5	16·2	22·0	14·9	19·2	29·9
Potato tubers	32·2	38·8	37·2	35·1	70·7	87·5	80·4	107·0	123·4	107·8	143·1	162·6
Kale	63·0	98·7	73·9	118·0	52·6	92·6	66·4	119·0	166·5	92·3	150·3	207·5
Ley	135·3	126·5	128·2	106·8	192·4	191·5	253·9	221·0	209·3	240·8	244·3	220·0
Permanent grass	70·8	114·3	63·2	129·1	68·8	138·9	86·1	132·6	204·1	130·6	189·9	244·2
Phosphorus												
Wheat grain	9·7	10·3	12·6	10·4	12·0	11·9	14·1	16·3	15·9	15·9	17·1	16·7
Wheat straw	1·6	1·6	3·0	3·2	1·6	1·8	2·7	3·4	4·1	3·1	5·0	5·9
Barley grain	5·7	6·3	8·4	8·3	6·3	6·8	8·9	11·2	12·7	11·4	13·9	13·8
Barley straw	0·9	1·2	1·4	1·8	1·1	1·0	1·5	1·8	2·1	1·7	2·3	3·2
Potato tubers	3·4	4·2	5·0	4·2	7·7	8·0	11·5	13·4	14·1	15·1	19·2	20·4
Kale	5·6	7·0	12·0	14·6	5·4	6·9	10·9	16·3	18·3	14·1	23·3	25·2
Ley	10·7	10·8	15·4	13·8	13·8	13·8	23·4	22·7	22·1	20·9	25·2	24·6
Permanent grass	10·0	8·9	10·4	18·0	8·7	13·4	15·0	18·1	22·2	19·8	25·3	29·1
Potassium												
Wheat grain	13·7	14·6	15·3	13·1	15·9	17·3	17·3	20·7	21·0	19·8	20·7	21·1
Wheat straw	15·4	16·4	19·4	14·2	35·7	46·5	39·5	55·8	67·0	53·2	93·5	109·7
Barley grain	10·3	11·9	13·0	13·4	11·8	14·3	14·5	18·6	20·8	18·1	21·9	21·9
Barley straw	10·3	13·3	14·5	10·8	28·4	34·1	29·9	37·2	43·6	39·3	57·8	77·0
Potato tubers	21·1	24·9	27·9	19·0	90·3	90·0	109·0	113·1	123·3	159·1	209·1	221·9
Kale	50·5	58·6	66·4	69·5	62·7	80·4	96·7	144·8	164·2	142·9	226·6	262·8
Ley	60·1	65·0	64·5	54·5	170·8	170·7	204·1	193·8	194·2	197·8	266·0	254·8
Permanent grass	42·2	31·5	34·9	41·3	82·3	152·6	104·4	150·1	169·5	189·0	272·2	309·7

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APPENDIX TABLE 3

The total amounts (lb/acre) of nitrogen, phosphorus (P) and potassium (K) applied for, and removed by, five crops in each five-year cycle of the experiment

	Treatments											
	O	N_1	P	N_1P	K	N_1K	PK	N_1PK	N_2PK	D	DN_1PK	DN_2PK
	Nitrogen											
1956–60												
Added	0·0	313·6	0·0	313·6	0·0	313·6	0·0	313·6	627·2	848·6	1162·2	1475·8
Removed	348·1	447·1	396·7	458·6	477·2	570·7	534·7	653·6	755·5	628·1	785·2	901·9
Difference	−348·1	−133·5	−396·7	−145·0	−477·2	−257·1	−534·7	−340·0	−128·3	+220·5	+377·0	+573·9
1961–65												
Added	0·0	313·6	0·0	313·6	0·0	313·6	0·0	313·6	627·2	592·4	906·0	1219·6
Removed	387·9	448·5	403·1	435·1	443·2	543·2	552·1	681·4	755·8	607·1	782·4	894·2
Difference	−387·9	−134·9	−403·1	−121·5	−443·2	−229·6	−552·1	−367·8	−128·6	−14·7	+123·6	+325·4
1966–70												
Added	0·0	313·6	0·0	313·6	0·0	313·6	0·0	313·6	627·2	602·4	916·0	1229·6
Removed	295·5	331·5	299·2	315·4	394·2	497·4	512·4	567·0	687·5	587·2	683·6	747·8
Difference	−295·5	−17·9	−299·2	−1·8	−394·2	−183·8	−512·4	−253·4	−60·3	+15·2	+232·4	+481·8
	Phosphorus											
1956–60												
Added	0·0	0·0	122·0	122·0	0·0	0·0	122·0	122·0	122·0	157·8	279·8	279·8
Removed	39·0	45·5	57·2	56·2	52·1	54·3	68·1	76·5	80·3	76·6	94·3	97·2
Difference	−39·0	−45·5	+64·8	+65·8	−52·1	−54·3	+53·9	+45·5	+41·7	+81·2	+185·5	+182·6
1961–65												
Added	0·0	0·0	122·0	122·0	0·0	0·0	122·0	122·0	122·0	110·4	232·4	232·4
Removed	36·7	39·3	58·0	57·4	44·2	46·3	71·1	86·3	89·9	76·6	101·3	110·0
Difference	−36·7	−39·3	+64·0	+64·6	−44·2	−46·3	+50·9	+35·7	+32·1	+33·8	+131·1	+122·4
1966–70												
Added	0·0	0·0	122·0	122·0	0·0	0·0	122·0	122·0	122·0	156·1	278·1	278·1
Removed	37·3	39·8	58·4	55·1	47·7	49·8	80·2	92·2	97·4	93·5	122·3	122·7
Difference	−37·3	−39·8	+63·6	+66·9	−47·7	−49·8	+41·8	+29·8	+24·6	+62·6	+155·8	+155·4
	Potassium											
1956–60												
Added	0·0	0·0	0·0	0·0	464·8	464·8	464·8	464·8	464·8	1120·2	1585·0	1585·0
Removed	171·2	211·3	202·7	193·8	351·1	380·0	389·7	430·9	474·5	571·6	767·0	829·3
Difference	−171·2	−211·3	−202·7	−193·8	+113·7	+84·8	+75·1	+33·9	−9·7	+548·6	+818·0	+755·7
1961–65												
Added	0·0	0·0	0·0	0·0	743·7	743·7	743·7	743·7	743·7	638·8	1382·5	1382·5
Removed	193·5	200·4	221·7	196·7	417·0	457·0	513·3	616·3	669·0	608·0	893·8	979·0
Difference	−193·5	−200·4	−221·7	−196·7	+326·7	+286·7	+230·4	+127·4	+74·7	+30·8	+488·7	+403·5
1966–70												
Added	0·0	0·0	0·0	0·0	929·5	929·5	929·5	929·5	929·5	957·0	1886·5	1886·5
Removed	179·6	202·1	238·2	193·2	479·3	522·5	630·1	705·4	758·9	710·9	1026·1	1099·4
Difference	−179·6	−202·1	−238·2	−193·2	+450·2	+407·0	+299·4	+224·1	+170·6	+246·1	+860·4	+787·1