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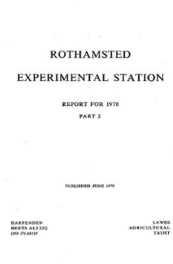
Rothamsted Experimental Station Report for 1978 Part 2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PART 2

Results from the Woburn Reference Experiment II. Yields of the Crops and Recoveries of N, P, K and Mg from Manures and Soil, 1970-74

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Results from the Woburn Reference Experiment II. Yields of the Crops and Recoveries of N, P, K and Mg from Manures and Soil, 1970–74

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The experiment was begun in 1960 on the sandy-silty loam (overlying Lower Greensand) of Stackyard Field at Woburn, Beds. Its purpose was to measure the long-term effects of N, P and K fertilisers and of farmyard manure (FYM) (applied alone and with fertilisers) on a range of crops, using very small plots (5·8 m^2). The results obtained from 1960 to 1969 have already been published (Widdowson & Penny, 1972; Williams, 1973) and complement those given here, which provide equivalent data from the third 5-year cycle of the experiment. Because leaf symptoms, firstly in sugar beet and then in potato leaves, were confirmed as Mg deficiency by analysis, a Mg test was included from 1967 onwards, by broadcasting Epsom salts over half of each suger-beet and potato plot in spring.

This paper gives only a brief and factual account of results from 1970 to 1974 and should therefore be read in conjunction with our previous paper.

Design and measurements

We continued to grow sugar beet, spring barley, a clover–grass ley, potatoes and winter oats each year and also a long ley (until 1973) and soft fruit. Each crop was given all combinations of two amounts (0 *v.* 1) of N, P and K in the standard eight-plot factorial design and also a double amount of N (N2) with P and K. FYM was tested alone (Code D) and with fertilisers supplying both single and double amounts of N (DN1PK and DN2PK). The treatments were allocated to six rows of a 12 × 12 latin square.

Each year the yields of each crop were measured and samples of them were taken to measure dry matter and N, P and K contents. Additionally, the penultimate leaflets were removed from 20 stems on each half-plot of potatoes in July and their Mg concentrations measured, as were the Mg contents of the mature potato tubers and of sugar-beet tops at harvest. From these values the amounts of N, P, K and Mg that the crops removed were calculated. Additionally the nutrient contents of each batch of FYM were measured, and these, together with the crop uptakes, were used to construct a nutrient balance sheet over the 5-year cycle. Finally, the crop uptakes were used to assess the efficiency of the nutrients in fertilisers and in FYM, as judged by apparent recovery.

Experimental method

The FYM was dug down each autumn for sugar beet and potatoes and spread each spring for the long ley and the fruit. P and K fertilisers were broadcast during winter and N and Mg in spring. The crop varieties chosen were: barley, Julia (ethirimol dressed); rotation ley, Hungarapoly red clover plus S.22 Italian ryegrass; potatoes, Desiree; oats, Peniarth; sugar beet, Klein E. The long ley was a composite mixture; the strawberries, Cambridge Vigour; blackcurrants, Wellington XXX and gooseberries, Careless.

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Manuring. 63 kg P_2O_5 ha^{-1} (27·4 kg P) as triple superphosphate and 251 kg K_2O ha^{-1} (208·5 kg K) as potassium bicarbonate were applied to each crop. Amounts of N given as ammonium nitrate for each were (in kg ha^{-1}):

	Spring barley	Rotation ley	Potatoes	Winter oats	Sugar beet	Long ley	Soft fruit
N1	63	31	126	63	126	188	63
N2	125	63	251	125	251	376	125

The N was divided into two equal dressings for barley, oats, potatoes and sugar beet, and in three for the long ley. Epsom salts were broadcast (50 kg Mg ha^{-1}) over one half of each sugar beet and potato plot in spring and over the other half after each of these crops had been harvested. Thus 100 kg Mg ha^{-1} was applied in 5 years to all plots in the arable sequence, and also to the long ley. Basal calcium carbonate was broadcast in 1970 to maintain soil pH at or near 7.0 and basal boron (5 kg ha^{-1}) was sprayed over sugar beet each year after singling.

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 Auto Analysis using the method of Fogg and Wilkinson (1958) after ashing and dissolving in 0·06N-HCl.

Potassium by Unicam SP.90A after dry ashing and solution in 0.06N-HCl.

Magnesium by atomic absorption, with strontium as releasing agent, using a Unicam SP.90A flame spectrophotometer, after dry ashing and solution in 0.06N-HCl.

Yields

Effects of N, P and K fertilisers and FYM. To facilitate comparisons between the relative responsiveness of the different crops to added nutrients and their relative abilities to obtain nutrients from the soil, most yields are presented as dry matter. However, Appendix Table 1 also shows the fresh yields of roots, tops and tubers, the yield of sugar from the sugar beet and yields of grain at 15% moisture content. Appendix Table 2 shows that the maximum dry matter yield of most crops was near to 10 t ha^{-1}, whereas that of sugar beet (roots and tops) reached 18 t ha^{-1}. Maximum yields of dry matter were obtained only where fertilisers and FYM were given together, but maximum yields of grain (though not of straw) were obtained from N2PK fertilisers alone.

Responses to N, P and K. All the crops, other than the clover–grass ley, required fertiliser N to yield well. However, the increase from the first increment of N was far larger than that from the second (Table 1), which enhanced yields mainly of foliage and of straw and not those of grain or roots. In general FYM either diminished or had little effect on the response to the double rate of fertiliser N, but potatoes gave three times more response to fertiliser N on plots where FYM had been given, than where it had not, probably because the amount of K added as fertiliser (208 kg K ha^{-1}) was far too little to meet the needs of the potato crop. Hence the additional K added by the FYM (532 kg K ha^{-1}, Table 6) allowed the full crop response to N.

By contrast, fertiliser P increased yields little, even of potatoes, even though no P

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TABLE 1

Responses to N, P and K fertilisers (means for 1970–74)

	Yields without fertiliser or FYM	Increases in the yield of dry matter (t ha^{-1}) from: N1 (N1PK-PK)	N2-N1 (N2PK-N1PK)	N2-N1 (in presence of D) (DN2PK-DN1PK)	P (N1PK-N1K)	K (N1PK-N1P)
Barley						
grain	1·54	2·08	0·39	−0·04	0·32	2·31
straw	1·18	2·10	1·17	0·65	0·43	1·66
Oats						
grain	1·65	1·57	0·42	−0·02	0·32	0·09
straw	1·75	2·74	1·07	1·35	0·73	1·18
Potato						
tubers	2·28	3·01	0·87	3·09	0·98	3·76
Sugar-beet						
tops	2·29	2·25	1·71	1·61	0·01	0·49
roots	3·66	3·90	0·65	0·78	−0·05	3·87
Rotation						
ley	4·09	0·84	0·15	0·20	1·07	4·60
Long ley (1970–73)	2·22	4·51	1·08	0·54	−0·02	2·02

D = FYM was applied at 50 t ha^{-1} for sugar beet and potatoes and at 25 t ha^{-1} for long ley

had been given to certain plots since 1960. However, fertiliser K greatly increased the yield of all the crops, other than oats grain.

Main effects and interactions of N, P and K fertilisers. The data in Table 2 were obtained in the conventional way by subtracting yields from four of the eight factorial treatments

TABLE 2

Main effects and interactions of N, P and K fertilisers on five arable crops, 1970–74

	Dry matter (t ha^{-1}): N	P	K	NP	NK	PK	NPK	s.e.	Coeff. of variation (%)
Oats									
grain	1·57**	0·15	0·04	0·08	−0·03	0·14	−0.06	±0·116	15·2
straw	2·08**	0·21	0·58*	0·24	0·33	0·19	0·08	±0·145	16·1
Barley									
grain	1·19**	−0·06	1·02**	−0·12	0.78**	0·26*	0·24*	±0·080	11·1
straw	1·39**	0·03	0·76**	0·00	0·50**	0·18	0·22	±0·093	14·4
Potato									
tubers	1·24**	0·30	1·93**	0·14	1·29**	0·20	0·34	±0·223	20·9
Sugar-beet									
roots	2.29**	−0·19	2·09**	−0·13	1·51**	0·04	0·24	±0·184	11·3
tops	2·02**	−0·07	0·14	−0·06	0·20	0·06	0·09	±0·099	9·5
Rotation									
ley	1·01**	0·37	4·31**	0·12	−0·28	0·59*	−0·01	±0·165	7·8

*, ** Significant at probability level of 1 and 0·1% respectively

(2^3) from the other four. There were highly significant main effects from N on each crop, from K on all except oats, but none from P. The NK interaction was sizeable and significant with barley, potatoes and sugar beet; for potatoes it was as large as the main effect of N. The PK interaction was again positive and significant at the 0·1% level on barley and the clover–grass ley. By contrast the NP interaction was never significant

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and sometimes negative, underlining the limiting effects of K shortage on this site. Nearly all the three-factor interactions were positive and that of barley was significant.

Responses to farmyard manure. Table 3 shows that FYM always increased yields either directly in the year of application or later as a residue. FYM generally increased yields less when NPK fertilisers also were given, than when they were not, except with potatoes, where FYM increased tuber yields more with the N2PK fertiliser dressing than with the N1PK or nil dressings. This implies that potassium was the most important constituent in the FYM for the potato crop, for the only difference between the two dressings of fertiliser was in the amounts of N that they supplied.

TABLE 3

Mean increase in yield (t ha^{-1} of dry matter) from FYM (D) tested with and without NPK fertilisers from 1970 to 1974

	Without NPK fertiliser (D-O)	With NPK fertiliser: N at single rate (DN1PK-N1PK)	With NPK fertiliser: N at double rate (DN2PK-N2PK)
Direct effects			
Potato tubers	3·47	1·54	3·76
Sugar-beet			
tops	1·56	1·27	1·17
roots	4·29	2·27	2·40
Long ley (1970–73)	2·06	1·31	0·77
Residual effects (one year later)			
Barley			
grain	1·19	0·40	−0·03
straw	0·98	0·68	0·16
Oats			
grain	0·56	0·32	−0·12
straw	0·75	0·54	0·82
Residual effects (two years later)			
Rotation ley	4·57	0·86	0·91

Responses to Mg by potatoes and sugar beet. Appendix Table 3 shows that whereas Mg greatly and consistently increased the yields of potato tubers on plots given K, it had little effect where K was omitted and where yields therefore were small. The yield of sugar-beet roots and tops was increased by Mg mainly on plots given N or N and K, and not with K alone. The largest increases in yield were of the order of 4 t ha^{-1} of potato tubers and 2 t ha^{-1} of sugar-beet roots. Table 4 shows how on average the N, P

TABLE 4

Mean effects of Mg on the yields of potatoes and sugar beet 1970–74 in the absence and presence of N, P and K fertilisers

Fertiliser tested	N1 Without	N1 With	P Without	P With	K Without	K With
Potatoes, total tubers (t ha^{-1}) fresh weight	1·36	1·93	1·28	2·01	0·23	3·06
Sugar-beet roots (t ha^{-1}) fresh weight	−0·01	1·56	0·46	1·09	0·65	0·90
Sugar-beet tops (t ha^{-1}) fresh weight	−0·10	0·48	0·23	0·14	0·13	0·24

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and K fertilisers influenced response to Mg on the eight plots testing them in factorial combination. K and Mg interacted strongly for potatoes and N and Mg interacted for sugar beet. Mean responses to Mg (over these eight plots) were 1·64 t ha^{-1} of potatoes, 0·77 t ha^{-1} of sugar-beet roots and 0·19 t ha^{-1} of sugar-beet tops. The increases from Mg were smaller where both FYM and NPK fertilisers were given, than where NPK fertilisers were given alone, presumably because the FYM added almost as much Mg (Table 6) as we applied as fertiliser.

Amounts of N, P, K and Mg applied 1970–74

By fertilisers. The amounts of N, P, K and Mg applied each year have been given previously.

By farmyard manure. Table 5 shows the percentages of dry matter and of N, P, K and Mg in the batches of FYM used (always made by cattle in yards at Rothamsted) and

TABLE 5

Chemical analysis of FYM, 1970–74

Cropping year	Dry matter %	% in dry matter of N	P	K	Mg
1970	26·30	2·97	0·78	4·26	0·33
1971	22·25	3·12	0·52	4·56	0·34
1972	25·05	3·37	0·52	4·48	0·31
1973	24·65	3·14	0·52	4·28	0·32
1974	22·06	3·08	0·67	4·43	0·36
Mean	24·06	3·14	0·60	4·40	0·33

Table 6 the amounts added by the standard 50 t ha^{-1} dressing. Nutrient content of the FYM dressings varied little from year to year; and always supplied a major part of the K demand of the crops (Table 10); the far smaller content of Mg greatly enhanced uptake of Mg both by potatoes and by sugar-beet tops (Appendix Table 5).

TABLE 6

Annual amounts (kg ha^{-1}) of N, P, K and Mg supplied by 50 t ha^{-1} of FYM, 1970–74

Cropping year	N	P	K	Mg
1970	392	103	563	44
1971	349	58	510	38
1972	424	65	564	39
1973	389	64	530	40
1974	342	74	491	40
Mean	379	73	532	40

Amounts of N, P and K removed from the soil by individual crops, 1970–74. Table 7 shows the amounts of N removed from the soil by crops given P and K, of P by crops given N and K, and of K by crops given N and P fertilisers. The mean annual amounts of N, P and K removed by the five arable crops from this soil were 43·2, 14·1 and 37·4 kg ha^{-1} respectively, thus explaining the large responses to N and K fertilisers shown in Table 1.

Differences between the abilities of the different crops to obtain N, P and K from the soil are also worth comment. Thus the Broad Red Clover in the rotation ley fixed 3·5 times as much N (214 kg ha^{-1}) as the wild white clover did (60 kg ha^{-1}) in the long ley.

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TABLE 7

Mean annual amounts of N, P and K (kg ha⁻¹) removed from the soil, by crops given the other two elements as fertiliser, 1970–74

	N	P	K
Barley			
grain	24	11·1	9
straw	6	1·3	6
Oats			
grain	31	11·1	14
straw	7	2·0	16
Potato			
tubers	46	9·8	25
Sugar-beet			
tops	37	9·8	39
roots	23	8·5	23
Rotation			
ley	214*	16·9	54
Mean	43	14·1	37
Long ley	60	13·1	40

* includes contribution by clover

In spite of this, the potatoes (which followed the rotation ley) obtained only 46 kg N ha^{-1} from the soil (on plots given P and K only), which contained many clover roots. This was only 16 kg N ha^{-1} more than the barley (which followed the potatoes) recovered.

The potato tubers obtained less P from this soil than any other crop, but responded more to P than any other crop, though the magnitude of the response, relative to that from N or K was small. Removal of K from soil differed greatly with crop, with sugar beet obtaining by far the most (62 kg K ha^{-1}) and oats twice as much as barley.

Recovery of N, P and K from the fertilisers. Table 8 gives the apparent recoveries by the crops of the N, P and K from fertilisers, calculated by subtracting the amounts of

TABLE 8

The apparent recoveries (%) of N, P and K from fertilisers by five arable crops and a long ley, 1970–74

	Percentage recovery of			
Test crop	N1	N2	P	K
Barley (grain and straw)	61	55	8	20
Oats (grain and straw)	60	56	10	33
Potato tubers	50	37	11	47
Sugar-beet (tops and roots)	64	65	11	73
Rotation ley	—	—	19	85
Long ley	—	—	19	64
Mean	59	53	12	52

each nutrient in crops grown without it, but with the other two, from amounts in crops given all three, and expressing this difference as a percentage of that given as fertiliser.

The recovery of N by the two leys cannot be given because the plots given P and K, but not N, were rich in clover, which fixed atmospheric N (Appendix Table 4). Of the N given for the barley and oats more than half (58%) was recovered in grain plus straw. Little more was recovered from the single than from the double amounts of N. Sugar beet recovered N rather more efficiently than potatoes, but as two-thirds of the N was in the tops, much of this is likely to be wasted unless the tops are conserved. Where

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sugar-beet tops are ploughed-in much of this N is at risk either through denitrification or by leaching (Widdowson, 1974), thus reinforcing the advice that large dressings of N are not justified for sugar beet. No more than 10% of the fertiliser P was recovered by the four arable crops and only 20% by the leys; neither ley responded greatly to P (Table 2).

The oats and the barley recovered less K than the other crops did, presumably because much of the K in the growing crop was returned to the soil. However, both the clover–grass ley and the sugar beet recovered more than two-thirds of the 208 kg of K given, whilst the long ley recovered almost two-thirds of it. Surprisingly the potatoes, which responded the most to fertiliser K, recovered less than either sugar beet or the leys.

Recovery of N, P and K from FYM. In this experiment FYM is applied at 50 t ha^{-1} for only two of the five crops (potatoes and sugar beet) in the five-course arable sequence, but at 25 t ha^{-1} to the long ley annually. It is tested alone and also with the N1PK and with the N2PK fertiliser dressings. Potatoes and sugar beet both recovered a far smaller fraction of the N and the K from FYM (Table 9) than they did from fertilisers (Table 8), but the same fraction of P. As 50 t ha^{-1} of FYM contained on average 380 kg N, 73 kg P and 530 kg K (Table 6) and the N2PK fertiliser dressing supplied 250 kg N,

TABLE 9

The apparent recoveries (%) of the N, P and K in FYM (D) by five arable crops and a long ley, 1970–74

	FYM applied					
	Alone (D-O)			With N2PK fertilisers (DN2PK-N2PK)		
% recovery of	N	P	K	N	P	K
FYM newly applied for						
Potatoes (tubers)	11	11	20	18	12	26
Sugar-beet (roots and tops)	16	16	24	17	12	31
Long ley	—	16	27	—	19	36
FYM applied for root crops 1 year ago						
Barley (grain and straw)	5	7	5	3	5	9
Oats (grain and straw)	3	6	8	2	7	9
FYM applied for potatoes 2 years ago						
Rotation ley	17	5	25	12	5	8

TABLE 10

The total amounts (kg ha^{-1}) of nitrogen (N), phosphorus (P) and potassium (K) applied for and removed by five crops grown in rotation at Woburn, 1970–74

	O	N1	P	N1P	K	N1K	PK	N1PK	N2PK	D	DN1PK	DN2PK
Nitrogen												
Added*	0	408	0	408	0	408	0	408	816	758	1166	1574
Removed	247	378	232	355	367	527	387	589	742	482	718	903
Difference	−247	+30	−232	+53	−367	−119	−387	−181	+74	+276	+448	+671
Phosphorus												
Added	0	0	137	137	0	0	137	137	137	146	283	283
Removed	40	52	45	57	51	70	61	87	94	79	115	124
Difference	−40	−52	+92	+80	−51	−70	+76	+50	+43	+67	+168	+158
Potassium												
Added	0	0	0	0	1042	1042	1042	1042	1042	1064	2106	2106
Removed	189	205	190	187	486	646	516	727	785	625	1013	1222
Difference	−189	−205	−190	−187	+556	+396	+526	+316	+258	+439	+1093	+884

* As fertiliser, excludes N added by clover in rotation ley

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27 of P and 208 of K, both crops recovered far less N in total from FYM than from fertilisers. This is not surprising because the FYM was dug down in winter and therefore subject to leaching before the crops were planted. Appendix Table 4 shows that the absolute recoveries of P by sugar beet, potatoes and the leys from FYM and from fertiliser P were very similar but that those of K were smaller from FYM. The data in Table 9 show that these crops utilised the P and the K in the FYM as efficiently whether or not NPK fertilisers also were given, even though the amounts of P and K added were then far larger. Hence fertilisers did not diminish the value of P and K in FYM. Oats and barley recovered little residual N from FYM given the year before. Though the recoveries of P and K from FYM residues were small in relation to the amounts added by the FYM (Tables 9 and 10) they were larger in absolute terms than those from newly applied P and K fertilisers.

Amounts of N, P and K taken up by individual crops. These are shown in Appendix Table 4. The maximum amounts taken up were by crops given most nutrients (FYM plus fertilisers) which of course produced the largest yields. Even so, differences between the demands of the crops were large, particularly for N and for K. Sugar beet, potatoes and the long ley justified most N and were given the most; they removed the most N, P and K. All removed more K than N, and sugar beet in particular removed remarkably large amounts of K (max. 416 kg K ha^{-1}), three-quarters of which was in the tops. Thus the conservation of sugar-beet tops as animal feed rather than their use as a green manure (as at present) would greatly enhance the drain on soil K reserves and hence the need of K by subsequent crops. This fact should be taken account of in the presentation of our nutrient balance sheet (Table 10), because we removed all the sugar-beet tops from the plots. Note also that the clover–grass ley, which required no N, removed as much P and K as the long ley or the potatoes.

Amounts of N, P and K added to and removed from the soil in 5 years. Table 10 shows the total amounts of each of the nutrients added by FYM and by fertilisers and the amounts removed by the five arable crops in one cycle of the experiment. The nitrogen balance sheet takes no account of the fact that a large proportion of the total N removed was in the clover–grass ley (65–214 kg N ha^{-1}, Appendix Table 4). As this soil provided on average 43 kg N ha^{-1} (Table 1) and the clover ley given P and K fertilisers, but no N, removed 200 kg N ha^{-1} it appears that the clover nodules fixed at least 160 kg N ha^{-1} on these clover-rich plots. This almost halves the apparent loss of N in 5 years, even without taking into account the N contained in the clover roots, which were dug in for the following potato crop. There were large positive balances of N where FYM had been given, much of which was subject to leaching during winter, but which nevertheless increased the yields of the following crops. Balances of P and K are less difficult to interpret. Those for P were always positive where P was given annually even though the amount applied (27 kg P ha^{-1}) was far less than usually would be given. By contrast we applied far more fertiliser K (1040 kg K ha^{-1} in 5 years) than usually would be given, and crops given the N2PK fertiliser dressing removed 785 kg K ha^{-1} in 5 years. Of this, 190 kg K ha^{-1} apparently was provided by the soil, leaving the balance (595 kg ha^{-1}) to presumably be provided by fertiliser. This represents an apparent recovery of 57% of the fertiliser given, a value somewhat larger than that of 52% for the N1PK fertiliser treatment (Table 8). Evidently therefore a range of arable crops can be expected to recover only 50–60% of K added as fertiliser, even on potash-responsive sites like this one. Our conclusion therefore must be that our large annual dressings of K were justified, for both yields and uptakes were larger still where FYM also was given. However, there appeared to be less need of fertiliser K where FYM was applied, because the two 50 t

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dressings supplied 1064 kg K ha^{-1} thus almost doubling the amount of K added during the 5 years (2106 kg K ha^{-1}); of this extra 1064 kg K, 437 kg were apparently recovered by the crops growing on the DN2PK plots (41% of that given in the FYM). Bearing in mind the larger yields of sugar beet and especially of potatoes on these plots (Appendix Table 1) it is difficult to argue that this additional K simply encouraged the luxury uptake of K, without enhancing yields. The fact that the FYM also supplied Mg and N, both limiting nutrients on this soil, makes it impossible to determine the true merits of the K added by the FYM.

Mg in potato leaves and tubers and in sugar-beet tops. Appendix Table 5 shows that the potato leaves contained most Mg where neither fertiliser nor FYM was given. Table 11

TABLE 11

Mean percentages of Mg in potato leaves in July, in the mature potato tubers and in mature sugar-beet tops, together with mean uptakes, 1970–74

Mean of 4 years for potato leaves and 5 years for potato tubers and sugar beet

	N		P		K	
	Without	With	Without	With	Without	With
			% Mg in potato leaves			
Without Mg	0·39	0·43	0·41	0·41	0·66	0·16
With Mg	0·47	0·53	0·48	0·52	0·78	0·21
			% Mg in potato tubers			
Without Mg	0·08	0·08	0·08	0·08	0·07	0·10
With Mg	0·08	0·08	0·08	0·08	0·07	0·10
			Mg (kg ha^{-1}) in potato tubers			
Without Mg	2·2	3·4	2·6	3·0	1·6	4·0
With Mg	2·6	3·8	3·0	3·3	1·7	4·6
			% Mg in sugar-beet tops			
Without Mg	0·24	0·32	0·27	0·27	0·34	0·19
With Mg	0·26	0·36	0·29	0·32	0·40	0·22
			Mg (kg ha^{-1}) in sugar-beet tops			
Without Mg	5·3	12·6	9·1	8·7	11·4	6·5
With Mg	5·9	15·2	10·2	10·8	13·5	7·5

shows how on average N, P and K fertilisers influenced the concentration of Mg and uptakes of it by the two crops, with and without the test dressings of magnesium. The Mg content of the potato tubers was no guide to its availability in the soil, but applying Epsom salts increased % Mg a little, and sufficiently to remove Mg deficiency symptoms in the leaves. N fertilisers slightly increased % Mg in the leaves, whether or not Mg was given, whereas P fertilisers had little effect on it, and K fertilisers decreased Mg concentrations in the leaves by a factor of four (to 0·16%). These low values were obtained despite the dressings of 100 kg ha^{-1} each 5 years, with another 80 kg ha^{-1} in FYM. In spite of the basal applications of Epsom salts, 2 years previously, the test dressing of Mg continued to increase potato yields wherever K fertilisers were given and even where FYM also was given (Appendix Table 3). These increases in yield from the Mg fertiliser were reflected in large uptakes of Mg by potato tubers on the FYM plots (max. 12·2 kg ha^{-1}, Appendix Table 5).

N increased % Mg in sugar-beet tops at maturity, and again P had little or no effect. Potassium fertiliser greatly diminished % Mg in sugar-beet tops to values of less than 0·20%; Mg fertiliser increased Mg concentrations little (Table 11). Because Mg fertiliser increased yields little (Appendix Table 3) Mg uptakes were increased most by N, perhaps reflecting the large response to N by sugar-beet tops.

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Practical implications

The value of FYM on a sandy soil. Table 12 shows how dependent yields of sugar beet and potatoes were on the combination of FYM and fertilisers on this poor sandy soil, despite the fact that the fertiliser dressings used were quite large, e.g. 251 kg N ha^{-1} for these two crops. Other experiments made with potatoes on this field, to test this point, showed that yields from fertiliser alone could be as large as from a combination of FYM and fertilisers, providing that the large amounts of fertiliser required were fully and deeply incorporated into the soil (Widdowson, Penny & Flint, 1974). Shortage of N coupled with the inability of this soil to supply more than minimal amounts of K (Table 7) and subsequently Mg also, implies that soils like this one can support only small and unacceptable crops (Table 12) unless generous amounts of N and K and adequate Mg are given. Yields declined over the 15-year period where neither N nor K was given, but were maintained when these fertilisers were supplied. Thus, yields of crops given NPK fertilisers each year from 1960 to 1974, either alone or together with FYM, increased and tended to stabilise around the 1965–69 values. Hence yields could be maintained by fertilisers alone, albeit at a lower level than on plots where FYM also was given (Table 13). However, interpretation is not simple, for doubling the dressing of fertiliser N (N2PK) gave yields very similar to those from FYM plus the single amount of N (FYM + N1PK). The mean increase in dry matter yield from FYM over these 15 years was 1·41 t ha^{-1} of dry matter where N1PK was given and 1·72 t ha^{-1} where N2PK was applied (Table 13). The value of these increases depends on the relationship between the cost of fertilisers and the cost of FYM, but it seems unlikely that farmers would ever supply as much K in fertilisers as they would do in normal FYM dressings.

TABLE 12

Yields (t ha^{-1}) of crops grown without and with farmyard manure, 1970–74

Crop	Potato tubers(1)		Winter oats grain(2)		Sugar-beet roots(1)		Spring barley grain(2)		Clover–grass ley(3)		Long ley(3)	
FYM (D)	—	D	—	(D)	—	D	—	(D)	—	(D)	—	D
Fertilisers												
None	10·3	26·2	1·94	2·60	16·0	33·3	1·81	3·21	4·09	8·66	3·88	5·91
N1PK	28·6	38·3	3·95	4·33	34·4	43·7	4·64	5·10	9·77	10·63	8·52	8·99
N2PK	33·0	52·4	4·45	4·31	38·3	48·2	5·09	5·06	9·92	10·83	9·40	10·94

(1) = fresh weight; (2) = weight at 15% moisture content; (3) = dry weight

TABLE 13

Mean yield of dry matter of five crops in each 5-year cycle of the experiment

Years	1960–64	1965–69	1970–74	Mean
Without FYM				
N1PK	8·22	8·76	8·79	8·59
N2PK	9·07	10·61	10·08	9·92
With FYM				
N1PK	9·27	10·35	10·37	10·00
N2PK	10·53	12·49	11·89	11·64

Conclusions

The fact that yields in the third crop cycle were no larger than in the second, suggests that nutrient resources in these plots are no longer limiting yields and that further yield

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increases will only come from the understanding and control of other limiting factors, i.e. by the use of better varieties, cultural techniques or better pathogen control. Since normal crop hygiene techniques were used on all our crops, it seems that better varieties are the most likely way of increasing output on this freely drained sandy soil, other than through the application of irrigation water in times of moisture stress during summer.

Summary

Results are given from the third 5-year cycle (1970–74) of the experiment begun in 1960 on the sandy-silty loam of Stackyard Field at Woburn, testing N, P, K and Mg fertilisers and also FYM on five arable crops grown in rotation and on a long ley.

N greatly increased yields of all crops other than the clover-rich rotation ley. P increased yields little. K greatly increased yields of barley, potatoes, sugar beet and of the clover–grass ley, and was more limiting for barley and for potatoes than was N. Mg increased yields of sugar beet and even more of potatoes.

Farmyard manure was applied alone and with NPK fertilisers for sugar beet, potatoes and a long ley; the other crops valued its residues. Yields of all crops other than potatoes were increased more by FYM when it was applied alone than together with NPK fertilisers, but potato yields were increased more by FYM when NPK fertilisers also were given. FYM residues increased barley grain yields except when much fertiliser N was given (N2PK).

Nutrient balance sheets showed that in 5 years two 50 t ha^{-1} applications of FYM supplied almost exactly as much K (1064 kg ha^{-1}) as was applied as fertiliser (1042 kg ha^{-1}) and similar amounts of P (145 kg ha^{-1} *v.* 137 kg ha^{-1} in fertilisers). Amounts of P removed by the crops were always less than those given, so sizeable balances remained in the soil even though the ratio of P_2O_5:K_2O added in fertilisers on plots receiving both, was 1:4, far wider than generally is used. However, this ratio appeared appropriate for the P and K demands of the crops grown in this experiment. The total amounts (kg ha^{-1}) of N, P and K removed from 1970 to 1974 ranged from 230 to 900 of N, 40 to 124 of P and 190 to 1200 of K, the largest uptakes being associated with the largest crops.

The experiment also measured the mean annual amounts of N, P and K supplied by this soil. These were (in kg ha^{-1}) 43 of N, 14 of P and 37 of K, values similar to those obtained in the previous cycle of the experiment, with the exception that the K supplying capacity had declined from 49 kg K ha^{-1} $year^{-1}$ in 1965–69 to 37 kg K ha^{-1} $year^{-1}$ in 1970–74.

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APPENDIX TABLE 1

Mean yields of agricultural produce from combinations of N, P and K fertilisers and FYM (D) tested on four arable crops and on soft fruit in the Woburn Reference experiment, 1970–74

	Treatments											
	–	N1	P	N1P	K	N1K	PK	N1PK	N2PK	D	DN1PK	DN2PK
	Fresh produce ($t\ ha^{-1}$)											
Potato tubers*	10·28	11·37	11·46	11·12	14·24	23·69	14·60	28·60	33·02	26·23	38·27	52·39
Sugar-beet roots*	15·99	21·16	16·69	18·58	19·11	34·14	18·05	34·44	38·27	33·29	43·66	48·18
Sugar-beet tops*	10·96	21·75	11·24	20·61	11·21	23·24	11·11	23·01	35·97	22·13	33·16	45·63
	Grain ($t\ ha^{-1}$) at 15% moisture content											
Barley	1·81	2·73	1·87	1·92	2·08	4·26	2·19	4·64	5·09	3·21	5·10	5·06
Oats	1·94	3·67	1·79	3·85	1·80	3·58	2·10	3·95	4·45	2·60	4·33	4·30
	Sugar ($kg\ ha^{-1}$)											
Sugar beet*	2640	3392	2737	2952	3195	5958	3034	5828	6258	5869	7644	8052
	Gooseberries, blackcurrants (kg per bush) and strawberries (kg per seven plants) (Yields are means of 5 years (1970–74) for gooseberries and blackcurrants and of 3 years (1971–73) for strawberries)											
Gooseberries	1·36	2·05	3·29	1·83	4·27	5·16	3·92	5·61	5·17	6·79	6·18	7·25
Blackcurrants	0·87	0·68	1·04	1·11	0·78	1·28	0·81	1·58	1·37	1·13	1·55	2·38
Strawberries	1·45	1·29	0·93	1·43	2·23	2·05	2·84	2·34	2·01	2·73	1·28	1·76

* Averaged over with and without Mg on each treatment for all years (1970–74)

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APPENDIX TABLE 2

Mean yields of dry matter (t ha⁻¹) from combinations of N, P and K fertilisers and FYM (D) tested on five arable crops and on a long ley in the Woburn Reference experiment, 1970–74

	Treatments											
	–	N1	P	N1P	K	N1K	PK	N1PK	N2PK	D	DN1PK	DN2PK
Potatoes												
total tubers*	2·28	2·43	2·58	2·33	3·05	5·11	3·08	6·09	6·96	5·75	7·63	10·72
Sugar-beet												
tops*	2·29	4·27	2·31	3·98	2·27	4·46	2·22	4·47	6·18	3·85	5·74	7·35
roots*	3·66	4·80	3·85	4·20	4·44	8·12	4·17	8·07	8·72	7·95	10·34	11·12
Barley												
grain	1·54	2·32	1·59	1·63	1·77	3·62	1·86	3·94	4·33	2·73	4·34	4·30
straw	1·18	2·28	1·24	1·91	1·47	3·14	1·47	3·57	4·74	2·16	4·25	4·90
Oats												
grain	1·65	3·12	1·52	3·27	1·53	3·04	1·79	3·36	3·78	2·21	3·68	3·66
straw	1·75	3·34	1·61	3·53	1·89	3·98	1·97	4·71	5·78	2·50	5·25	6·60
Rotation ley	4·09	5·25	3·74	5·17	8·08	8·70	8·93	9·77	9·92	8·66	10·63	10·83
Total in 5 years	18·44	27·81	18·44	26·02	24·50	40·17	25·49	43·98	50·41	35·81	51·86	59·48
Long ley†	2·22	5·91	1·82	5·52	3·16	7·56	3·03	7·54	8·62	4·28	8·85	9·39

* Averaged over with and without Mg on each treatment for all years (1970–74)
† Ley dug in 1974, yields are for 1970–73

APPENDIX TABLE 3

Mean yields of potatoes and of sugar beet without magnesium and the increases from applying magnesium in the Woburn Reference experiment, 1970–74

	Main treatments											
	–	N1	P	N1P	K	N1K	PK	N1PK	N2PK	D	DN1PK	DN2PK
					Potatoes, total tubers (t ha⁻¹) fresh weight							
Yields without Mg	9·76	11·30	11·28	10·63	12·89	22·11	13·10	26·12	31·44	23·87	36·18	51·91
Increases from Mg	0·39	−0·20	0·06	0·66	2·36	2·60	2·66	4·65	2·53	4·10	3·21	0·62
					Sugar-beet roots (t ha⁻¹) fresh weight							
Yields without Mg	15·84	21·06	16·86	17·36	19·10	33·49	18·08	33·29	37·26	33·75	42·76	47·32
Increases from Mg	0·29	0·20	−0·33	2·44	0·03	1·30	−0·05	2·29	2·02	−0·93	1·80	1·73
					Sugar-beet tops (t ha⁻¹) fresh weight							
Yields without Mg	10·61	22·42	11·57	19·71	11·23	22·44	11·32	23·09	35·05	22·72	31·04	45·76
Increases from Mg	0·69	−1·33	−0·66	1·81	−0·03	1·60	−0·42	−0·17	1·43	−1·17	4·24	−0·25

APPENDIX TABLE 4

Mean annual amounts (kg ha^{-1}) of nitrogen (N), phosphorus (P), and potassium (K) taken up by five arable crops and by a long ley grown with combinations of N, P and K fertilisers and FYM (D) in the Woburn Reference experiment, 1970–74

	Treatments											
	0	N1	P	N1P	K	N1K	PK	N1PK	N2PK	D	DN1PK	DN2PK
Nitrogen												
Barley												
grain	21·9	36·7	22·6	27·4	24·2	50·1	24·4	53·1	74·2	38·6	67·7	83·0
straw	6·0	13·4	5·7	16·0	6·6	12·6	5·7	15·2	24·9	8·7	18·7	29·4
Oats												
grain	29·6	53·2	25·8	54·7	25·9	51·0	31·0	58·2	78·9	38·1	67·2	72·4
straw	6·4	12·4	5·4	13·2	6·5	17·4	6·8	17·5	28·4	9·6	22·2	41·0
Potatoes												
total tubers	38·4	53·3	42·1	53·7	45·9	92·8	45·7	109·1	139·1	80·8	138·4	208·0
Sugar-beet												
tops	36·6	95·3	38·8	94·3	37·5	84·4	36·7	86·0	152·4	71·7	132·8	188·2
roots	21·3	34·9	21·6	30·2	24·8	53·2	22·6	53·9	70·6	47·7	74·6	99·0
Rotation ley	86·4	78·9	69·6	65·8	195·4	165·3	213·6	196·0	173·7	186·7	195·9	181·9
Long ley (1970–73)	36·5	127·6	31·8	127·8	57·9	144·7	59·6	145·0	217·8	68·8	186·6	240·0
Phosphorus												
Barley												
grain	5·4	7·2	5·8	5·3	6·5	11·1	7·1	12·8	13·8	10·0	16·3	15·2
straw	1·1	1·5	1·2	2·1	1·1	1·3	1·4	1·8	2·8	1·7	3·8	5·3
Oats												
grain	6·0	11·0	6·1	11·8	6·2	11·1	7·0	12·6	13·7	8·7	14·7	15·0
straw	2·3	1·4	3·3	2·5	2·7	2·0	3·4	3·2	3·1	4·1	5·5	7·0
Potatoes												
total tubers	5·1	5·5	6·3	5·7	7·4	9·8	8·0	12·8	12·9	12·9	17·3	21·5
Sugar-beet												
tops	5·6	9·7	7·2	12·2	5·1	9·8	6·3	11·5	15·4	10·2	16·8	19·7
roots	4·3	5·3	4·8	5·6	5·1	8·5	5·6	9·9	10·3	11·1	14·5	15·0
Rotation ley	9·7	10·4	10·4	11·8	16·8	16·9	22·0	22·2	21·9	20·7	25·7	25·8
Long ley	5·6	10·7	5·6	15·7	6·7	13·1	8·0	18·2	20·0	11·4	23·9	26·7
Potassium												
Barley												
grain	8·6	12·3	9·2	9·2	10·5	18·6	11·1	20·6	22·0	15·7	23·7	23·2
straw	7·3	7·7	8·1	5·9	18·4	33·6	18·7	37·3	46·6	26·8	59·5	92·4
Oats												
grain	7·9	13·4	7·1	14·2	7·0	13·9	8·9	15·7	16·2	10·9	17·9	18·6
straw	16·1	15·9	16·7	16·0	40·9	72·1	44·4	83·3	99·0	53·5	113·9	142·8
Potatoes												
total tubers	26·5	27·6	30·9	25·3	71·2	104·4	75·6	123·0	132·6	131·5	201·1	273·7
Sugar-beet												
tops	44·4	50·9	39·9	39·0	76·0	147·5	77·1	158·0	192·6	133·8	244·4	314·4
roots	21·9	24·5	22·3	23·3	30·5	55·3	31·1	57·1	60·7	61·4	86·3	101·8
Rotation ley	56·4	52·5	55·8	54·2	231·6	201·0	249·1	231·7	214·9	191·4	266·2	255·0
Long ley	34·0	45·3	30·7	39·8	69·0	172·6	72·0	172·4	185·0	106·6	257·8	282·2

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APPENDIX TABLE 5

The mean percentages of magnesium and mean amounts (kg ha⁻¹) of magnesium in potato leaves, dry potato tubers, and dry sugar-beet tops, in the Woburn Reference experiment, 1970–74

	Main treatments											
	0	N1	P	N1P	K	N1K	PK	N1PK	N2PK	D	DN1PK	DN2PK
						% Mg in leaves in July (1971–74)						
Potatoes												
Without Mg	0·65	0·67	0·67	0·64	0·13	0·20	0·12	0·20	0·27	0·23	0·21	0·25
With Mg	0·74	0·77	0·82	0·81	0·16	0·26	0·16	0·27	0·37	0·24	0·24	0·29
						% Mg in tubers						
Without Mg	0·07	0·07	0·07	0·07	0·10	0·10	0·10	0·10	0·10	0·10	0·11	0·11
With Mg	0·07	0·07	0·07	0·07	0·10	0·10	0·10	0·10	0·10	0·10	0·11	0·11
						Mg (kg ha⁻¹) in tubers						
Without Mg	1·5	1·6	1·7	1·5	2·7	4·5	2·8	5·8	6·5	5·3	7·8	11·5
With Mg	1·5	1·7	1·8	1·7	3·3	5·4	3·6	6·2	7·0	6·4	8·9	12·2
						% Mg in tops						
Sugar-beet												
Without Mg	0·28	0·42	0·32	0·36	0·17	0·20	0·18	0·21	0·22	0·33	0·24	0·26
With Mg	0·30	0·43	0·33	0·53	0·18	0·25	0·21	0·23	0·32	0·30	0·30	0·31
						Mg (kg ha⁻¹) in tops						
Without Mg	6·0	18·1	7·5	13·9	3·8	8·6	3·8	9·7	13·2	12·9	13·0	19·0
With Mg	7·2	18·1	7·6	21·2	4·1	11·5	4·6	9·9	20·4	11·0	18·4	23·2

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