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Iv. The Value to Arable Crops of Residues Accumulated from Superphosphate

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**The Value of Residues from Long-period Manuring at
Rothamsted and Woburn
IV. The Value to Arable Crops of Residues Accumulated from
Superphosphate**

A. E. JOHNSTON, R. G. WARREN and A. PENNY

The histories of the sites of these experiments, the form of the experiments and the crops grown, are described in paper III (page 22).

Yields

Cereals

Effect of seedbed dressings. Appendix Table 1 shows the yields of barley and spring wheat on the Exhaustion Land in 1957–58, of barley on Agdell in 1959–60 and at Woburn in 1960–62. On all but one site in one year the cereals responded to new P up to the maximum tested on starved soils without P residues; the exception was on the Wheat Site at Woburn in 1962 when, without new P fertiliser, this soil gave an anomalously large yield. On each site the response to new P was always greater in the wetter (total March–June rainfall) of the two years.

Table 1 shows that, at Rothamsted, yields of barley grain on starved soils without new P were small, 12 to 16 cwt/acre, and 50 lb/acre of new P increased them by 11 to 12 cwt/acre. The experiments were made with Plumage Archer, which in the Classical Barley Experiment on Hoosfield in 1964–66 gave similar yields to Maris Badger on poor soils but smaller ones with full NPK manuring. Table 1 also shows that the responses to new P

TABLE 1

Effect of a new dressing of 50 lb P/acre on the yields of barley grown on soils with and without P residues at Rothamsted and Woburn, 1957–62

	Grain, cwt/acre			
	Rothamsted		Woburn	
	Exhaustion Land mean 1957 & 1958	Agdell mean 1959 & 1960	Wheat Site mean 1960 & 1962	Barley Site mean 1960 & 1961
Starved soil				
Without new P	16.2	12.3	24.6	17.2
With new P	27.8	23.0	25.2	20.4
Response to new P ¹	11.6	10.7	0.6	3.2
Enriched soil				
Without new P	24.8	27.2	29.2	24.1
With new P	27.7	30.9	30.2	27.4
Response to new P ¹	2.9	3.7	1.0	3.3

¹ New P at 50 lb P/acre applied broadcast to the seedbed.

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were much smaller, only 3 to 4 cwt/acre, on Rothamsted soils containing residues of previous P manuring than on soils without residues. At Woburn, barley yielded more on the soils without residues, 17 to 25 cwt/acre, than at Rothamsted, and the responses to new P (1 to 3 cwt) were smaller.

Table 2 shows the yields on starved and enriched soils without new P; residues increased yields of barley grain by 9 to 15 cwt/acre at Rothamsted and 5 to 7 cwt at Woburn.

TABLE 2

Effect of P residues in the soil on the yields of cereals given no new P at Rothamsted and Woburn, 1957-62

Soil given no new P and with	Grain, cwt/acre				
	Rothamsted			Woburn	
	Exhaustion Land mean 1957 & 1958		Agdell mean 1959 & 1960 Barley	Wheat Site mean 1960 & 1962 Barley	Barley Site mean 1960 & 1961 Barley
	Barley	Spring wheat			
No residues	16.2	19.0	12.3	24.6	17.2
P residues	24.8	22.4	27.2	29.2	24.1
Increase due to P residues in the soil	8.6	3.4	14.9	4.6	6.9

Some of the soils with residues behaved atypically. Because it is not yet possible to explain the low yields or lack of response to new fertiliser, the yields are given only in the Appendix Tables. On Agdell plots 1 and 2 and on both plots 8, but especially on the Wheat Site at Woburn, yields of cereals were smaller than on the other enriched soils and there was no response to new P. All these plots became very acid before 1920 and liming just before the microplot experiments were made did not restore their productivity. Warren and Johnston (1962) discussed the poor yields of barley in 1961 on plot 1 on Agdell when, on microplots not given a fresh dressing of P, the young plants became very yellow; similar young barley plants on Rothamsted Farm were diagnosed deficient in N and/or K. Though these yellow plants on Agdell contained less N and K than green plants they also contained very much less P than the green plants on microplots given a fresh dressing of P; the poor physical condition of the soil after the very wet winter slowed the growth of roots of the yellowed plants and prevented them from getting enough P from the residues. Thus, on a poor seedbed, barley may need a fresh dressing of phosphate when the soil contains only a moderate amount of soluble P. At Woburn there were no obvious differences in the condition of the seedbeds on the various plots and each year barley made good early growth. In 1962, sugar beet on plot 8 on the Wheat Site showed signs of magnesium deficiency, as did cereals in 1967 in a new experiment on this site. In a test of Mg in 1968, Bolton (1969) showed that giving Mg increased % Mg in wheat plants in May, but it increased grain yield too little to explain the small barley yields on plot 8.

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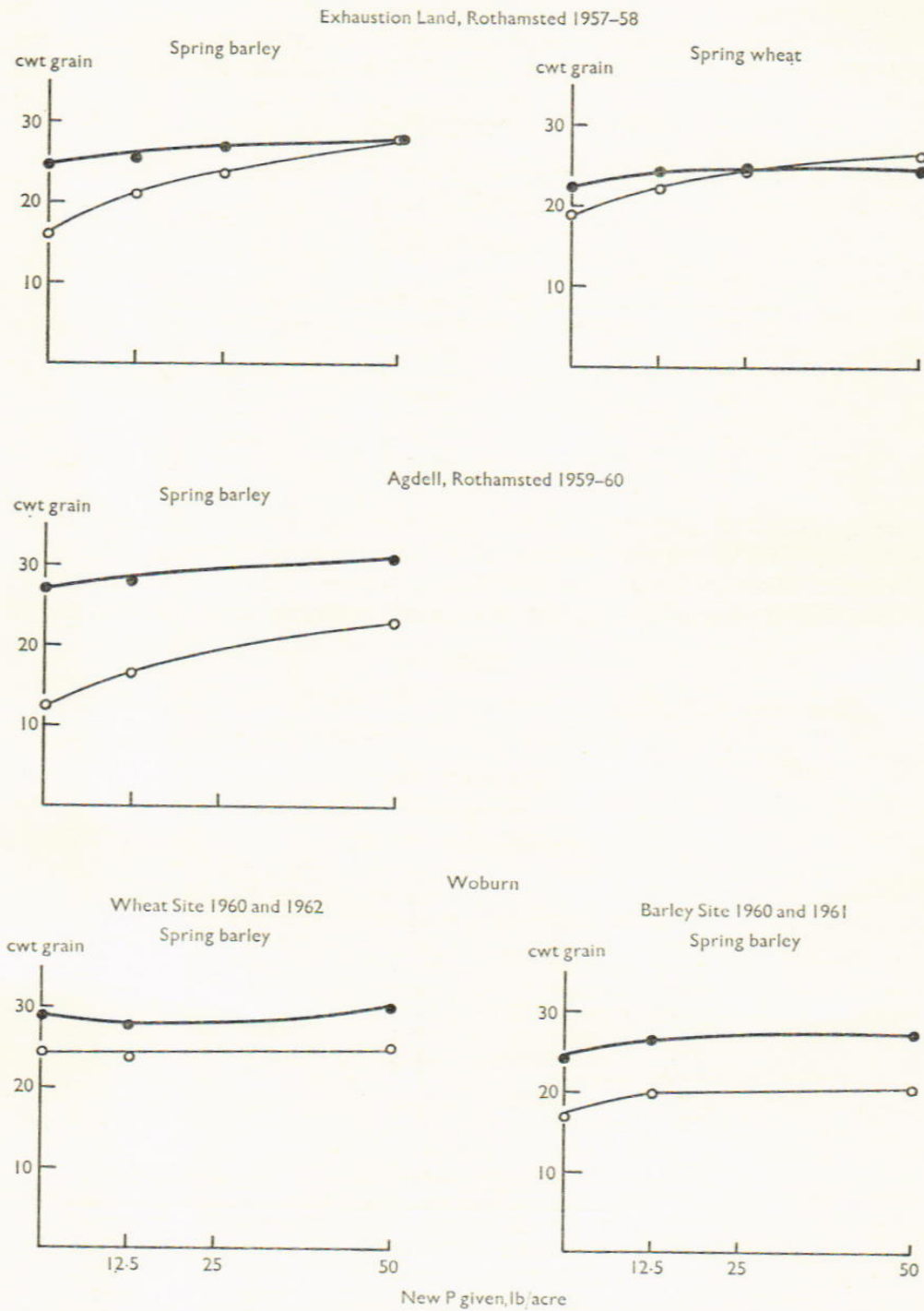


FIG. 1. Effect of P residues and new P on the average yield per acre of cereal grain, Rothamsted and Woburn, 1957-62.

(With ● and without ○ P residues.)

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However the small yields of potatoes on the Wheat Site at Woburn may have been caused by Mg deficiency, though the leaves of the plants showed no symptoms.

Fig. 1 shows the response curves to new P on both starved and enriched soils. Only on the Exhaustion Land can the P residues be valued in terms of

TABLE 3

Effect of new broadcast dressings of P and a new residue of P on barley, Agdell, 1960

P given lb/acre		Plots 3 and 4 with old P residues	Plots 5 and 6 no P residues
In 1959	In 1960		
0	0	23.0	10.5
0	12.5	23.4	12.6
0	50.0	26.8	16.7
0	75.0	27.0	19.0
50	0	24.6	16.8
50	75.0	26.6	21.0

a fresh broadcast dressing of P having the same effect on yield, for barley this was 30 lb P, for spring wheat 12 lb P. On the other three sites yields on the enriched soils without new P were larger than on starved soils with new P.

In the first year of the Agdell experiment enriched soils without new P

TABLE 4

Effect of new P, ploughed in or broadcast on the seedbed, on barley yields at Rothamsted and Woburn, 1961-62

P given lb/acre		Grain, cwt/acre	
		Rothamsted	
		Agdell, mean 1961-62	
		Plots 3, 4 with P residues	Plots 5, 6 no P residues
0		31.1	22.0
37.5	seedbed	34.2	27.4
75	seedbed	34.0	23.6
37.5	ploughed in	33.8	25.0
75	ploughed in	29.6	29.0
37.5	ploughed in	31.6	27.8
+37.5	seedbed		
75	ploughed in	33.2	32.4
+75	seedbed		
		Woburn	
		Wheat Site 1962	
		Plot 9 with P residues	Plot 7 no P residues
		Barley Site 1961	
		Plot 9 with P residues	Plot 7 no P residues
0		31.6	29.1
12.5	seedbed	29.1	27.5
50	seedbed	32.1	27.2
0		31.7	26.3
12.5	ploughed in	31.5	26.0
50	ploughed in	29.9	32.3
		25.3	17.9
		26.6	20.6
		27.9	21.3
		25.3	22.2
		25.7	23.7
		24.9	25.5

VALUE OF RESIDUES FROM SUPERPHOSPHATE

gave such larger yields than starved soils with new P, that the experiment was modified in 1960 to test 75 lb of new P/acre and the residues of the 50 lb P/acre applied in 1959. Even with 75 lb P/acre, yields did not equal those on enriched soil without new P (Table 3); on the starved soil in 1960 the residue of the 50 lb P/acre applied in 1959 yielded as well as the same dressing newly applied and this residue also enhanced the effect of the new 75 lb/acre P.

Comparison of ploughed-in and seedbed dressings for barley. Because there was this large effect of the ploughed-in residue of a single dressing of P fertiliser, ploughed in and seedbed dressings of P fertilisers were compared on Agdell and at Woburn in 1961 and 1962. Table 4 shows that on Agdell there was a maximum yield of 33 to 34 cwt grain on the enriched soil and this was only approached (32 cwt grain) on the starved soil with a combined dressing of 75 lb P ploughed in plus 75 lb P to the seedbed. At Woburn on the Wheat Site, maximum yield of 31 to 32 cwt grain on the enriched soil was only equalled on the starved soil by ploughing in 50 lb P (the largest amount tested); on the Barley Site, 26 to 28 cwt of grain was obtained with residues and again this was only equalled on soils without residues by ploughing in 50 lb of fresh P.

Potatoes

Effect of seedbed dressings. Often when FYM was given to potatoes the soil was drawn into ridges and the manure was put in the furrows before setting the potatoes. The ridges were then split back to make new ridges over the potato sets. Cooke (1949) showed that, when potatoes were planted this way, fertilisers could be applied by various techniques that allow some degree of fertiliser placement. In our experiments, the fertiliser was put in the *bottoms* of the furrows before planting (Cooke, 1949, Method C), this was done on the Exhaustion Land and Agdell where the potatoes were set by hand, but at Woburn the potatoes had to be machine planted and so the fertilisers were applied on the flat seedbed immediately before planting, which distributed the fertiliser through the ridge as in Method A. Appendix Table 2 shows the yields on the Exhaustion Land in 1957–58, on Agdell in 1959–60, and at Woburn in 1960–62.

Potatoes on all sites and in all years on soils with and without P residues responded to new P up to the largest amount tested. Table 5 shows that at Rothamsted where the yields on starved soils were small (5 tons/acre) the responses to 50 lb new P/acre were between 5 and 8 tons. The enriched soils on Agdell produced 12 tons/acre but those on the Exhaustion Land only 8 tons/acre. On these enriched soils responses to new P were smaller than on the starved soils. At Woburn yields on the starved soils (14 tons/acre) were larger than at Rothamsted but the responses to new P on both starved and enriched soils were small (about 1 ton/acre).

Table 6 shows the yields with and without P residues when new P was not given and the large yields with the residues. Fig. 2 gives the response curves to new P.

On the Exhaustion Land the residues could be valued in terms of a new dressing of P; for the potatoes this was no more than 5 lb P/acre. On the

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TABLE 5

Effect of a new dressing of 50 lb P/acre on the yield of potatoes grown on soils with and without P residues at Rothamsted and Woburn, 1957-62

	Tubers, tons/acre			
	Rothamsted		Woburn	
	Exhaustion Land mean 1957 & 1958	Agdell mean 1959 & 1960	Wheat Site mean 1960 & 1962	Barley Site mean 1960 & 1961
Starved soil				
Without new P	5.1	4.8	13.8	14.1
With new P	13.0	10.1	14.6	15.8
Response to new P ¹	7.9	5.3	0.8	1.7
Enriched soil				
Without new P	8.4	11.9	16.7	15.8
With new P	13.0	15.2	18.0	16.6
Response to new P ¹	4.6	3.3	1.3	0.8

¹ New P at 50 lb P/acre given along the bottoms of the furrows before hand planting on the Exhaustion Land and Agdell, on the flat seedbed before machine planting at Woburn.

TABLE 6

Effect of P residues in the soil on the yields of potatoes given no new P at Rothamsted and Woburn, 1957-62

	Tubers, tons/acre			
	Rothamsted		Woburn	
	Exhaustion Land mean 1957 & 1958	Agdell mean 1959 & 1960	Wheat Site mean 1960 & 1962	Barley Site mean 1960 & 1961
Soil given no new P and with				
No residues	5.1	4.8	13.8	14.1
P residues	8.4	11.9	16.7	15.8
Increase due to P residues in the soil	3.3	7.1	2.9	1.7

TABLE 7

Effect of new broadcast dressings of P and a new residue of P on potatoes, Agdell, 1960

P given lb/acre		Tubers, tons/acre	
In 1959	In 1960	Plots 3 and 4 with old P residues	Plots 5 and 6 no P residues
0	0	16.0	6.1
0	12.5	17.4	8.7
0	50	20.1	12.6
0	75	20.2	13.6
50	0	17.3	10.0
50	75	20.1	14.6

other three sites yields on enriched soils without new P were more than on starved soils with new P, except at Woburn where the residues on the Barley Site could be valued at 50 lb new P/acre.

VALUE OF RESIDUES FROM SUPERPHOSPHATE

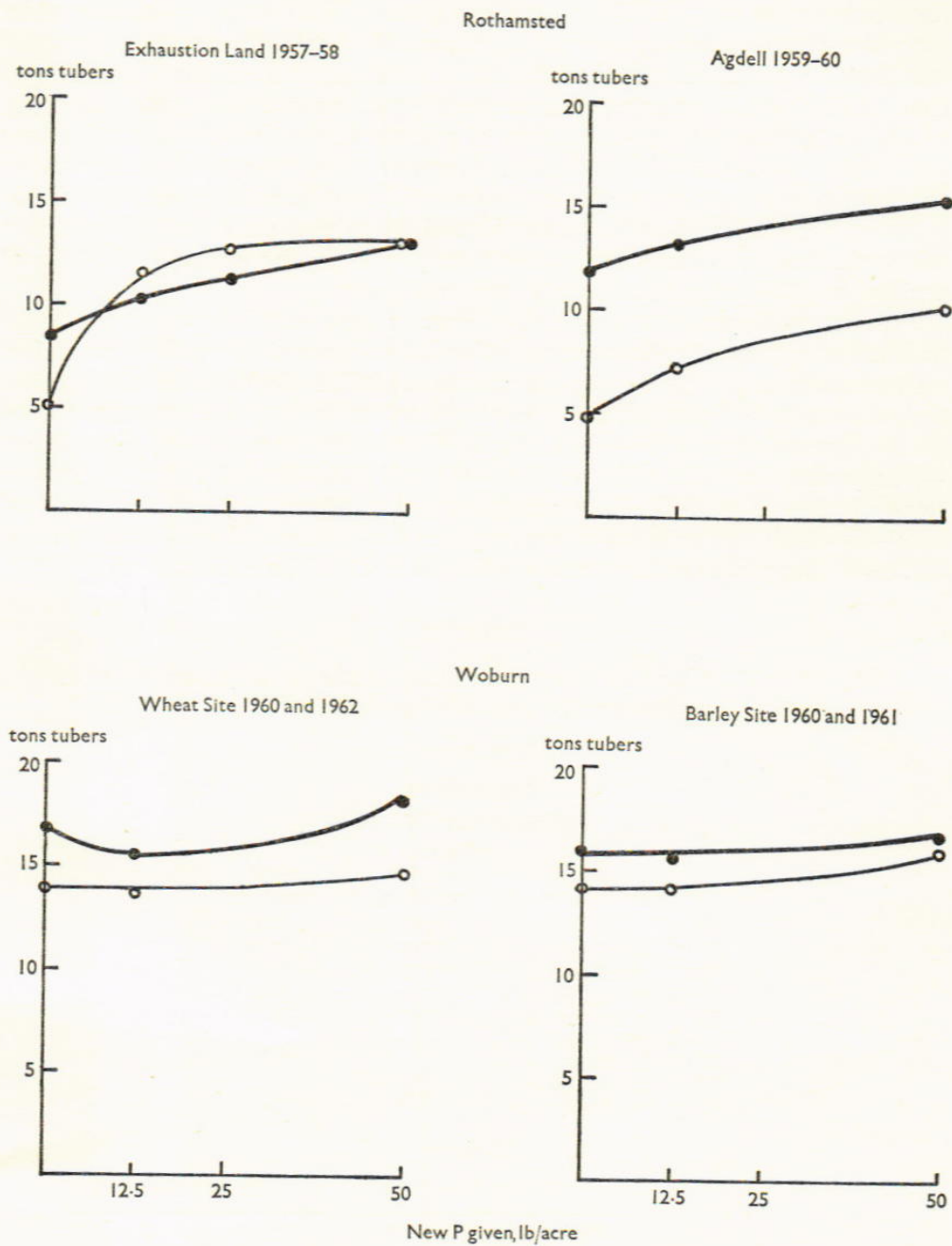


FIG. 2. Effect of P residues and new P on the average yield per acre of potato tubers, Rothamsted and Woburn, 1957-62.
(With ● and without ○ P residues.)

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When the Agdell experiment was modified in 1960, P was tested at 75 lb P/acre for potatoes. As Table 7 shows, on the enriched soils this did not further increase the yield, and on the starved soil, though 1 ton/acre more potatoes was obtained by increasing P from 50 lb to 75 lb, the yield was still less than on enriched soil without a new dressing of P. Table 7 also shows that, in 1960, on the starved soil the residues of the previous year's dressing of 50 lb P gave an extra 4 tons/acre of potatoes; even more interesting was that these one-year-old residues, together with the new dressing of 75 lb P/acre, gave more potatoes than would have been suggested by extrapolating the response curve to new dressings in that year. In 1960 on soils with residues potatoes gave a small response to the residue of 50 lb P applied in 1959 only when new P was not given.

Further evidence that single dressings of new fertiliser can have large residual effects on very impoverished soils but inconsistent effects on richer soils came from the yields of potatoes on Agdell. In 1961-62 on the starved soil without new P the yield of 7.8 tons/acre (Table 8) was 3 tons more than on the same plots in 1959-60 (Table 5). On the enriched soils of plots 3 and 4, the yields were the same in 1959-60 and 1961-62 (12.2 and 11.9 tons respectively). The 1961-62 microplots were superimposed on those of 1959-60 which had received some fertiliser P and the residue of this dressing increased the yield on the starved soil but not on the enriched soil.

TABLE 8

Effect of new P, ploughed in or broadcast on the seedbed, on potatoes at Rothamsted and Woburn, 1961-62

		Tubers, tons/acre		
		Rothamsted		
		Agdell, mean 1961-62		
P given lb/acre		Plots 3, 4 with P residues	Plots 5, 6 no P residues	
0		12.2	7.8	
37.5	seedbed	11.9	9.2	
75	seedbed	15.8	9.9	
37.5	ploughed in	12.6	9.4	
75	ploughed in	11.9	10.2	
37.5	ploughed in			
+37.5	seedbed	14.7	10.2	
75	ploughed in			
+75	seedbed	13.2	10.3	
		Woburn		
		Wheat Site 1962		Barley Site 1961
P given lb/acre		Plot 9 with P residues	Plot 7 no P residues	Plot 9 with P residues
0		14.8	12.5	13.7
12.5	seedbed	13.2	11.9	12.5
50	seedbed	16.4	12.8	14.1
0		15.3	11.0	12.3
12.5	ploughed in	13.4	13.3	15.3
50	ploughed in	14.5	15.2	14.1
				11.6
				12.5
				13.0

VALUE OF RESIDUES FROM SUPERPHOSPHATE

Comparison of ploughed-in and seedbed dressings. Ploughed-in and seedbed-dressings of fertilisers for potatoes were compared on Agdell and at Woburn (Table 8), but neither method of application was consistently superior. On the starved soil on Agdell, even a new dressing of 150 lb P/acre did not give the same yield as the enriched soil without new P, but at Woburn ploughing in 50 lb P/acre on the starved soil gave the same yield as the enriched soil without new P. However, on both sites a new dressing of P on the enriched soil gave a larger yield than the same amount of new P on the starved soil, except when the new P was ploughed in on the Wheat Site at Woburn.

Sugar beet

Effect of seedbed dressings. Sugar beet, which were grown on the Exhaustion Land and Agdell in the same years as the other crops, were grown at Woburn only in one year on each site. Appendix Table 3 gives the yields on the Exhaustion Land, 1957–58; on Agdell 1959–60; at Woburn 1961–62. Table 9 shows that, on the starved soils at Rothamsted, sugar

TABLE 9

Effect of a new dressing of 50 lb P/acre on the yield of sugar from beet grown on soils with and without P residues at Rothamsted and Woburn, 1957–62

	Sugar, cwt/acre			
	Rothamsted		Woburn	
	Exhaustion Land mean 1957 & 1958 plots 5 & 9	Agdell mean 1959 & 1960 plots 3, 4, 5, 6	Wheat Site 1962 plots 7 & 9	Barley Site 1961 plots 7 & 9
Starved soil				
Without new P	30.6	26.9	50.2	32.1
With new P	45.6	38.2	47.4	34.6
Response to new P ¹	15.0	11.3	-2.8	2.5
Enriched soil				
Without new P	45.2	46.0	51.0	43.0
With new P	47.8	47.8	54.3	43.6
Response to new P ¹	2.6	1.8	3.3	0.6

¹ New P at 50 lb/acre broadcast on the seedbed.

yields were increased from 31 to 46 cwt/acre on the Exhaustion Land and from 27 to 38 cwt on Agdell by a dressing of 50 lb P/acre. However, much of this increase was given by a new dressing of 25 lb P/acre. On the enriched soils, the response to new P was only 2–4 cwt sugar/acre. At Woburn the sugar-beet experiment was the most disappointing in the series. Beet was grown only for one year on each site, whereas for the other crops on each site there are averages of two results. Responses to new P were small and variable, but did not exceed 3.0 cwt sugar/acre on either the starved or enriched soils.

Table 10 shows the yields at Rothamsted without any new P, and the large increases in yield from the residues of P on the enriched soils. At Woburn, on the Barley Site, yield on starved soil (30 cwt/acre) was similar to

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that on the starved soils at Rothamsted and the residues in the enriched soil gave an extra 11 cwt sugar. On the Wheat Site in 1962, yields on both soils were much larger (50 cwt/acre) and the P residues gave no extra yield.

TABLE 10

Effect of P residues in the soil on the yield of sugar when no new P was given at Rothamsted and Woburn, 1957-62

	Sugar, cwt/acre			
	Rothamsted		Woburn	
	Exhaustion Land mean 1957 & 1958 plots 5, 9	Agdell mean 1959 & 1960 plots 3, 4, 5, 6	Wheat Site 1962 plots 7 & 9	Barley Site 1961 plots 7 & 9
Soil given no new P and with				
No residues	30.6	26.9	50.2	32.1
P residues	45.2	46.0	51.0	43.0
Increase due to P residues in the soil	14.6	19.1	0.8	10.9

Fig. 3 gives the response curves of sugar beet to new P on both starved and enriched soils at Rothamsted. The residues on the Exhaustion Land were equivalent to a new dressing of about 25 lb P/acre. On Agdell, taking the mean of the two years, the residues were worth much more than any new dressing of P tested, largely because of the large yield given by the residues in the first year, 1959. Table 11 shows that, in the second year,

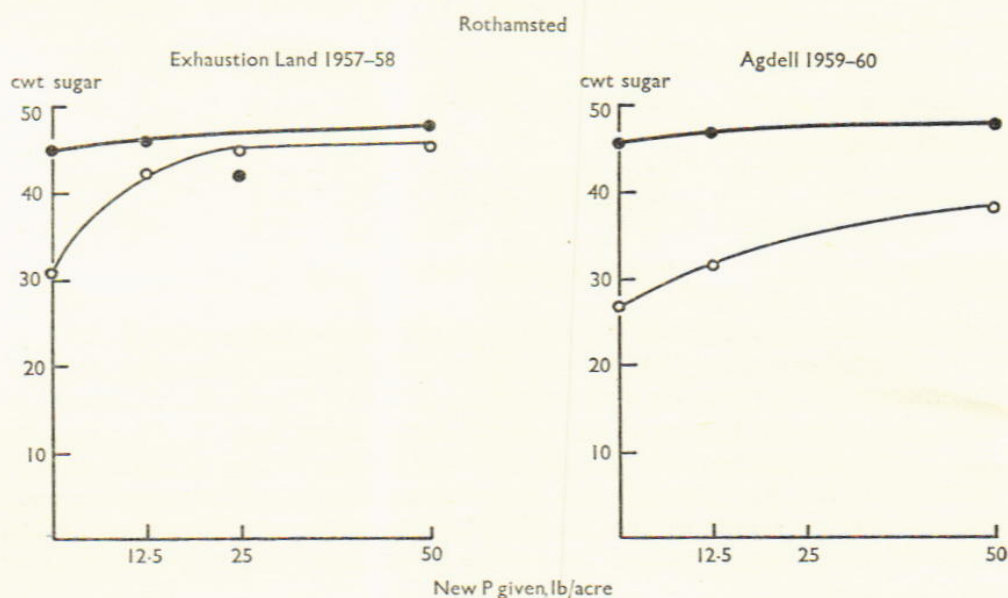


FIG. 3. Effect of P residues and new P on the average yield per acre of sugar, Rothamsted, 1957-60.

(With ● and without ○ P residues.)

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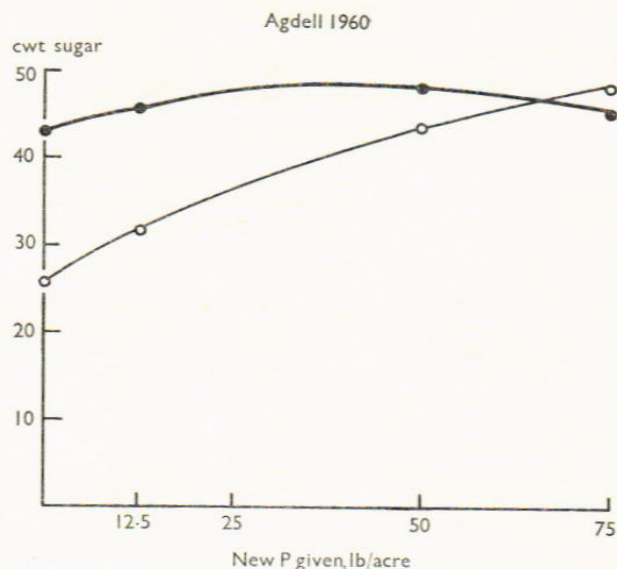


FIG. 3a. Effect of P residues and new P on the yield per acre of sugar, Agdell, 1960. (With ● and without ○ P residues.)

TABLE 11

Effect of new broadcast dressings of P and a new residue of P on sugar yields, Agdell, 1960

P given lb/acre		Plots 3 and 4 with old P residues	Plots 5 and 6 no P residues
In 1959	In 1960		
0	0	43.1	25.7
0	12.5	45.8	31.8
0	50	48.2	43.6
0	75	45.2	48.2
50	0	43.8	42.7
50	75	49.7	46.6

1960, when more new P was applied to the seedbed than in 1959, yields on starved and enriched soils were the same with 75 lb P/acre. From the response curves in Fig. 3a, the residue was valued at 50 lb new P.

Comparison of ploughed-in and seedbed dressings. The soils of Agdell are difficult to cultivate and often form a cloddy structure not easily penetrated by roots. The comparison of ploughed-in and seedbed dressings of fertilisers in 1961–62 showed that these soils yield more reliably when they contain residues. Table 12 shows that, for each treatment, the yield on the enriched soil was 8 to 13 cwt sugar/acre more than on the starved soils. The yields in Table 12 also indicate that the deep-rooting sugar beet responded more to ploughed in than to seedbed dressings of P. At Woburn, where the same comparison was made in the same years, yields varied too much to differentiate between ploughed in and seedbed dressings of P.

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TABLE 12

Effect of new P, ploughed in or broadcast on the seedbed, on sugar yields at Rothamsted, 1961-62

P given lb/acre		Sugar, cwt/acre	
		Agdell, mean 1961-62	
		Plots 3 and 4 with P residues	Plots 5 and 6 no P residues
0		64.5	54.7
37.5	seedbed	63.8	55.5
75	seedbed	67.6	60.2
37.5	ploughed in	75.2	64.4
75	ploughed in	71.8	58.3
37.5	ploughed in	74.8	61.8
+37.5	seedbed		
75	ploughed in	78.4	65.4
+75	seedbed		

Swedes and kale

Effect of seedbed dressings. These two crops were only grown in two years, 1957-58, and on one site, the Exhaustion Land. Appendix Table 4 shows yields of both crops were larger in 1958, the wetter of the years.

On the starved soil, swedes responded well (5.6 tons/acre) to the smallest amount of new P added (12.5 lb P/acre) and gave further increases of 1.9 and 1.8 tons from the next two amounts of P given. Kale behaved differently; it responded well (4.4 tons) to the smallest amount of P but only little more to further P. Table 13 shows that P residues increased yield of

TABLE 13

Effect of P residues in the soil on the yield of swedes and kale when no new P was given at Rothamsted on the Exhaustion Land, 1957-58

Soil given no new P and with	Tons/acre		
	Swedes		Kale
	Tops	Roots	
No residues	1.8	8.5	14.8
P residues	2.9	15.5	19.2
Increase due to P residues in the soil	1.1	7.0	4.4

both crops greatly, by 7.0 tons of swede roots and 4.4 tons of kale. On these enriched soils, the response to new P was much smaller than on the starved soils.

Fig. 4 shows that, with the largest amount of new P tested, the yield of swedes was the same on both starved and enriched soils but the largest amount of new P on the enriched soil gave 1.3 tons more kale than any other treatment. The response curves (Fig. 4) valued the residues as worth 20 lb broadcast new P for swedes and 15 lb P for kale.

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Exhaustion Land, Rothamsted 1957-58

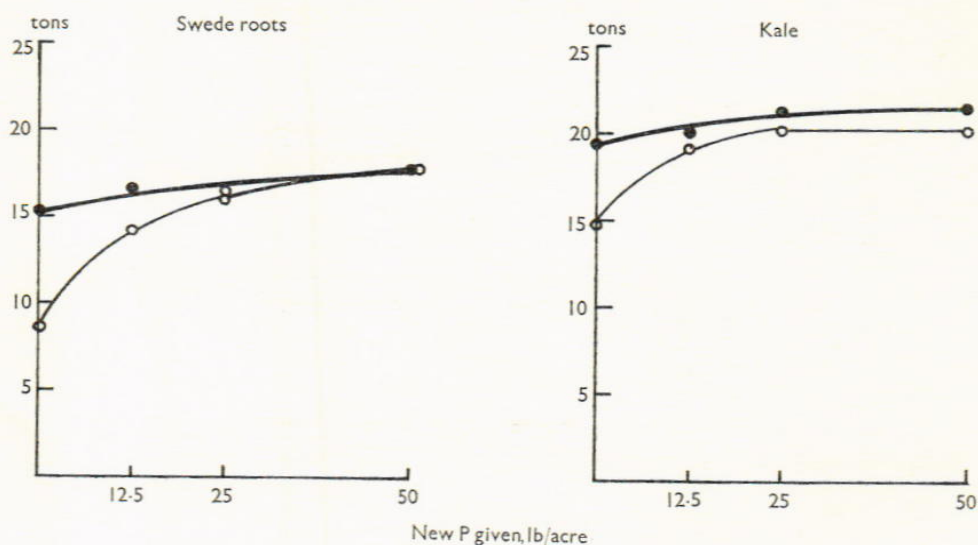


FIG. 4. Effect of P residues and new P on the average yield per acre of swede roots and kale, Rothamsted, 1957-58.

(With ● without ○ P residues.)

Discussion of the phosphorus tests

Table 14 shows the increases in yield of all crops from 50 lb P/acre applied as a broadcast dressing of superphosphate on all sites, excluding the poor yields on those Classical plots where previous treatment made the soils acid. At Rothamsted all crops on starved soil responded to new P very much more than on the enriched soils. On the Exhaustion Land, barley, spring wheat, potatoes and swedes yielded similarly on both starved and enriched soils when given a new dressing of 50 lb P/acre. Sugar beet and kale yielded rather more on soil with residues than on soil without. On the starved Agdell soils, none of the three crops, barley, potatoes and sugar beet, yielded as much when given 50 lb/acre new P as on the enriched soil without new P. At Woburn all crops, except for one test with sugar beet, responded to new P, though the responses were small, and were nearly the same on soils with and without residues. This was unexpected with potatoes, but this crop yielded very well at Woburn with all treatments.

At Rothamsted, residues did not lessen the responses to new P by potatoes as much as with other crops, and the response curves for potatoes were steeper than for other crops. This difference may mean that potatoes are less able than other crops to use phosphorus in the soil because the roots do not 'search' the soil mass so thoroughly, or it may be because the new P was placed in the furrows, under the seed tubers, whereas for the other crops it was broadcast and harrowed in about 2 in. deep.

At Woburn, potatoes without new P yielded very much more than at Rothamsted, suggesting that the roots were able to remove more nutrients from this light soil than from the heavy soil at Rothamsted. Smaller respon-

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TABLE 14
Effect of a broadcast dressing of 50 lb P/acre as superphosphate on the yields of crops grown on soils with and without P residues at Rothamsted and Woburn, 1957-62

	New P given lb/acre	Rothamsted				Woburn			
		Exhaustion Land mean 1957 & 1958		Agdell mean 1959 & 1960		Wheat Site mean 1960 & 1962		Barley Site mean 1960 & 1961	
		No residues	With P residues	No residues	With P residues	No residues	With P residues	No residues	With P residues
Barley grain, cwt	0	16.2	24.8	12.3	27.2	24.6	29.2	17.2	24.1
	50	27.8	27.7	23.0	30.9	25.2	30.2	20.4	27.4
	50 minus 0	11.6	2.9	10.7	3.7	0.6	1.0	3.2	3.3
Spring wheat grain, cwt	0	19.0	22.4	—	—	—	—	—	—
	50	26.2	24.0	—	—	—	—	—	—
	50 minus 0	7.2	1.6	—	—	—	—	—	—
Potatoes tubers, tons	0	5.1	8.4	4.8	11.9	13.8	16.7	14.1	15.8
	50	13.0	13.0	10.1	15.2	14.6	18.0	15.8	16.6
	50 minus 0	7.9	4.6	5.3	3.3	0.8	1.3	1.7	0.8
Sugar beet sugar, cwt	0	30.6	45.2	26.9	46.0	50.2	51.0	32.1	43.0
	50	45.6	47.8	38.2	47.8	47.4	54.3	34.6	43.6
	50 minus 0	15.0	2.6	11.3	1.8	-2.8	3.3	2.5	0.6
Swedes roots, tons	0	8.5	15.5	—	—	—	—	—	—
	50	17.8	17.9	—	—	—	—	—	—
	50 minus 0	9.3	2.4	—	—	—	—	—	—
Kale tons	0	14.8	19.2	—	—	—	—	—	—
	50	20.1	21.4	—	—	—	—	—	—
	50 minus 0	5.3	2.2	—	—	—	—	—	—

VALUE OF RESIDUES FROM SUPERPHOSPHATE

ses to new P at Woburn may have been because the new P was applied on the flat before the sets were machine planted.

When valued by the difference in yield between soils with and without residues, obtained with crops given enough N and K, the residues of old P dressings have considerable value at both Rothamsted and Woburn. Table 15 summarises these increases in yield of all crops on all sites. When

TABLE 15
Effect of old residues of fertiliser P dressings at Rothamsted and Woburn, 1957-62

Crop	Site	Years	Yield/acre		Increase due to P residues	% increase in yield due to residues
			No residues	With P residues		
Barley grain, cwt	Exhaustion Land	1957 & 1958	16.2	24.8	8.6	53
	Agdell	1959 & 1960	12.3	27.2	14.9	121
	Woburn					
	Wheat Site	1960 & 1962	24.6	29.2	4.6	19
	Barley Site	1960 & 1961	17.2	24.1	6.9	40
Spring wheat grain, cwt	Exhaustion Land	1957 & 1958	19.0	22.4	3.4	18
Potatoes tubers, tons	Exhaustion Land	1957 & 1958	5.1	8.4	3.3	65
	Agdell	1959 & 1960	4.8	11.9	7.1	148
	Woburn					
	Wheat Site	1960 & 1962	13.8	16.7	2.9	21
	Barley Site	1960 & 1961	14.1	15.8	1.7	12
Sugar beet sugar, cwt	Exhaustion Land	1957 & 1958	30.6	45.2	14.6	48
	Agdell	1959 & 1960	26.9	46.0	19.1	71
	Woburn					
	Wheat Site	1962	50.2	51.0	0.8	2
	Barley Site	1961	32.1	43.0	10.9	34
Swedes roots, tons	Exhaustion Land	1957 & 1958	8.5	15.5	7.0	82
Kale tons	Exhaustion Land	1957 & 1958	14.8	19.2	4.4	30

the extra yield is expressed as a percentage of the yield on the corresponding starved soil, the yield increases for all crops were between 18 and 65% on the Exhaustion Land and 70 and 150% on Agdell. At Woburn they were less, 2 to 40%.

Table 16 shows the value of the P residues in terms of an equivalent dressing of new P fertiliser, estimated from response curves to new P on starved soil; this could be done only for the residues on the Exhaustion Land. The range of amounts, 5 to 30 lb, is large, so though the residues must be the same chemically, they do not have one general value, but their value depends on the crop grown.

These results show the need for experiments on different soils. In the first experiments on the Exhaustion Land, yields of four of the six crops tested were the same on starved and enriched soils when the largest amount of new P was given. Therefore, given basal N and K, there was no difference between the two soils other than the amount of available P and this difference could be removed by applying 50 lb of fresh P/acre as superphosphate. In the second experiment, made on Agdell in 1959-60, the yields on

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TABLE 16

Value of fertiliser P residues expressed as broadcast dressing of P having the same effect on yield, the Exhaustion Land, Rothamsted, 1957-58

	lb P/acre
Barley, grain	30
Potatoes, tubers	5
Sugar beet, sugar	25
Spring wheat, grain	12
Swedes, roots	20
Kale	15

enriched soils without new P were larger than on starved soils with new P. This was true even when, in the second of the years, the largest amount of new P applied broadcast was increased to 75 lb P/acre. The results on the lighter soil at Woburn in 1960-62 were similar to those on Agdell.

Yields on the starved soils on Agdell could not be increased to those on enriched soils, even by ploughing in fertiliser P, but applying new P fertiliser this way gave larger yields than applying it to the seedbed. Analysis of soil samples, taken 9 in. deep, during early summer, showed that less of the ploughed in P had remained readily soluble, but because it was deeper it increased yield more than seedbed dressings. On some soils, therefore, P residues can give better yields than fertiliser P freshly applied at the rates and in ways usually recommended.

A third important result was that often all amounts of newly applied P fertiliser tested gave larger yields on soil enriched with residues than on starved soil.

Phosphorus concentration in the crops

Tables 17, 18 and 19 give the percentages of phosphorus in the dry matter of the crops grown in these experiments.

Cereals. The phosphorus concentration in the dry matter of cereals (Table 17) was smallest for those grown on Agdell where the new P gave the largest increase in yield. At Rothamsted, though new P fertiliser gave larger yields, it did not increase the P concentration in the grain. This contrasted strikingly with the effect of the residues, which consistently increased the concentration of P in the grain. Without new P, there was 0.24 to 0.29% P in grain grown on the starved soils and from 0.27 to 0.35% P on the enriched soils. Where dressings of new P are given annually on the Hoosfield Continuous Barley plots, the soil has much larger residues than those of these microplot experiments and the barley grain contains from 0.37 to 0.41% P, supporting the view that P distributed through the cultivated soil layer is more accessible to the plant than new broadcast dressings. Residues had little effect on % P in straw, whether or not new P was given. There was little difference between seedbed dressings and ploughed in new P on the % P in the grain.

Potatoes. On the Exhaustion Land and Agdell, where both residues and new P dressings gave large increases in yields of potatoes, the residues

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TABLE 17
Effect of P residues and new P on the percentage of P in grain and straw of cereals grown at Rothamsted and Woburn, 1957-62

	% P in dry matter															
	Rothamsted						Agdell									
	Exhaustion Land mean 1957 & 1958 P to seedbed			Mean 1961 & 1962			Mean 1959 & 1960			P ploughed in						
	Barley Grain	Barley Straw	Spring wheat Grain	Spring wheat Straw	Barley Grain	Barley Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
No new P given to soil with																
No residues	0.29	0.06	0.29	0.05	0.24	0.06	0.24	0.06	0.24	0.04	0.24	0.04	0.24	0.04	0.24	0.04
P residues	0.35	0.06	0.35	0.05	0.32	0.06	0.32	0.06	0.27	0.03	0.27	0.03	0.27	0.03	0.27	0.03
Effect of P residues	0.06	0	0.06	0	0.08	0	0.03	0	0.03	-0.01	0.03	-0.01	0.03	-0.01	0.03	-0.01
New P given (50 lb P/acre) ¹ to soil with																
No residues	0.31	0.05	0.31	0.04	0.25	0.06	0.22	0.06	0.22	0.02	0.22	0.02	0.24	0.02	0.24	0.02
P residues	0.35	0.06	0.35	0.05	0.32	0.05	0.25	0.03	0.25	0.03	0.25	0.03	0.28	0.03	0.28	0.03
Effect of P residues	0.04	0.01	0.04	0.01	0.07	-0.01	0.03	0.01	0.03	0.01	0.03	0.01	0.04	0.01	0.04	0.01
Effect of new P (50 lb P/acre) ¹ in the																
Absence of residues	0.02	-0.01	0.02	-0.01	0.01	0	-0.02	-0.01	-0.02	-0.02	0	-0.02	0	-0.02	0	-0.02
Presence of residues	0	0	0	0	0	-0.01	0	-0.01	0	0	-0.02	0	0	0.01	0	0
¹ 75 lb P/acre Agdell 1961-62.																
	Woburn															
	Wheat Site 1962			P ploughed in			Barley Site 1961			P ploughed in						
	P to seedbed	Barley	Straw	Barley	Grain	Straw	Barley	Grain	Straw	Barley	Grain	Straw	Barley	Grain	Straw	
No new P given to soil with																
No residues	0.32	0.06	0.28	0.04	0.36	0.06	0.36	0.06	0.34	0.04	0.36	0.04	0.34	0.04	0.34	0.04
P residues	0.36	0.05	0.32	0.04	0.36	0.04	0.36	0.04	0.36	0.04	0.36	0.04	0.34	0.03	0.34	0.03
Effect of P residues	0.04	-0.01	0.04	0	0	-0.02	0	-0.02	0	-0.02	0	-0.01	0	-0.01	0	-0.01
New P given (50 lb P/acre) to soil with																
No residues	0.36	0.06	0.30	0.04	0.34	0.04	0.34	0.04	0.34	0.04	0.32	0.04	0.32	0.04	0.32	0.04
P residues	0.37	0.06	0.36	0.04	0.36	0.04	0.36	0.05	0.36	0.05	0.36	0.04	0.36	0.04	0.36	0.04
Effect of P residues	0.01	0	0.06	0	0.02	0	0.02	0.01	0.02	0.01	0.04	0	0.04	0	0.04	0
Effect of new P (50 lb P/acre) in the																
Absence of residues	0.04	0	0.02	0	-0.02	0	-0.02	-0.02	-0.02	-0.02	0	-0.02	0	-0.02	0	-0.02
Presence of residues	0.01	0.01	0.04	0	0	0	0	0.01	0	0.01	0.02	0	0.01	0.02	0.01	0.01

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TABLE 18
Effect of P residues and new P on the percentage P in potatoes grown at Rothamsted and Woburn, 1957-62

	% P, in dry matter											
	Rothamsted						Woburn					
	Agdell			Mean 1961 & 1962			Wheat Site 1962			Barley Site 1961		
	Exhaustion Land mean 1957 & 1958 P in furrows	Mean 1959 & 1960 P in furrows	P to seedbed	P ploughed in	P to seedbed	P ploughed in	P to seedbed	P ploughed in	P to seedbed	P ploughed in	P to seedbed	P ploughed in
No new P given to soil with No residues	0.12	0.13	0.15	0.15	0.17	0.17	0.17	0.16	0.18	0.16	0.19	0.17
P residues	0.16	0.17	0.17	0.17	0.17	0.17	0.16	0.15	0.20	0.15	0.20	0.22
Effect of P residues	0.04	0.04	0.02	0.02	0.02	0.02	-0.01	-0.01	0.01	-0.01	0.01	0.05
New P given (50 lb P/acre) ¹ to soil with No residues	0.14	0.14	0.15	0.17	0.15	0.17	0.18	0.14	0.20	0.14	0.20	0.18
P residues	0.15	0.17	0.17	0.19	0.17	0.19	0.19	0.16	0.22	0.16	0.22	0.20
Effect of P residues	0.01	0.03	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02
Effect of new P (50 lb P/acre) ¹ in the Absence of residues	0.02	0.01	0	0.02	0	0.02	0.01	-0.02	0.01	-0.02	0.01	0.01
Presence of residues	-0.01	0	0	0.02	0	0.02	0.03	0.01	0.02	0.01	0.02	-0.02

¹ 75 lb P/acre Agdell 1961-62.

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increased P concentration in tuber dry matter more than did the newly applied P (Table 18). Residues increased % P by 15 to 30%, about the same as for cereals. At Woburn, where yields without P residues were large and where both residues and newly applied P gave only small increases in yield, there was no big change in the % P in dry matter.

Swedes, sugar beet, kale. Table 19 shows only the analyses of those crops grown on the Exhaustion Land. Without new P, % P in the crops on enriched soil was 40 to 100% more than on starved soil, a much larger increase than with cereals or potatoes. New P increased % P in the crops on starved soils to the concentrations in plants grown on enriched soil without new P, a result not achieved with cereals and potatoes. New P had much smaller effects with residues than without.

TABLE 19

Effect of P residues and new P on the percentage of P in sugar beet, swedes and kale grown on the Exhaustion Land, Rothamsted, 1957-58

	Sugar beet		Swedes		Kale
	Tops	Roots	Tops	Roots	
No new P given to soil with					
No residues	0.19	0.08	0.29	0.16	0.20
P residues	0.26	0.13	0.41	0.34	0.28
Effect of P residues	0.07	0.05	0.12	0.18	0.08
New P given (50 lb P/acre) to soil with					
No residues	0.24	0.13	0.42	0.32	0.26
P residues	0.26	0.14	0.44	0.32	0.32
Effect of P residues	0.02	0.01	0.02	0	0.06
Effect of new P (50 lb P/acre) in the					
Absence of residues	0.05	0.05	0.13	0.16	0.06
Presence of residues	0	0.01	0.03	-0.02	0.04

Phosphorus content of the crops

Tables 20 to 23 show the uptakes of phosphorus by the harvested parts of the crops grown.

Cereals. Without new P, uptake of P by the whole crop from starved soils ranged from 4 to 6 lb P/acre at Rothamsted and 7 to 9 lb P at Woburn (Table 20). On enriched soils 8 to 10 lb P was taken up at Rothamsted and 9 to 11 lb P at Woburn, so the residues provided 3 to 6 lb P at Rothamsted and 1 to 2 lb P at Woburn. With new P, uptakes on the Exhaustion Land were much the same from starved and enriched soils, 9 to 11 lb P, but on Agdell and at Woburn the presence of residues increased the uptake of P because yield was increased by residues on these sites but not on the Exhaustion Land.

Potatoes. The tubers of the potato crop from the starved soil on the Exhaustion Land and on Agdell 1959-60, contained only 3 lb P/acre (Table 21). On Agdell in 1961-62 the uptake was larger, 5.6 lb P, probably

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TABLE 20
Effect of P residues and new P on the amount of P in the grain and straw of cereals grown at Rothamsted and Woburn, 1957-62

	Rothamsted												Woburn														
	Exhaustion Land mean 1957 & 1958 P to seedbed				Spring wheat				Mean 1959 & 1960 P to seedbed				Mean 1961 & 1962 P to seedbed				Barley Site 1961				Barley Site 1962						
	Barley		Total		Grain		Straw		Total		Grain		Straw		Total		Grain		Straw		Total		Grain		Straw		Total
No new P given to soil with	4.4	1.4	5.8	5.2	1.2	6.4	2.8	1.0	3.8	5.0	0.6	5.6	5.0	0.6	5.6	5.0	0.6	5.6	5.0	0.6	5.6	5.0	0.6	5.6	5.0	0.6	5.6
No residues	8.5	1.9	10.4	7.6	2.0	9.6	8.4	1.4	9.8	7.9	0.7	8.6	7.9	0.7	8.6	7.9	0.7	8.6	7.9	0.7	8.6	7.9	0.7	8.6	7.9	0.7	8.6
P residues	4.1	0.5	4.6	2.4	0.8	3.2	5.6	0.4	6.0	2.9	0.1	3.0	2.9	0.1	3.0	2.6	0.1	2.7	2.6	0.1	2.7	2.6	0.1	2.7	2.6	0.1	2.7
Effect of P residues																											
New P given (50 lb P/acre) ¹ to soil with	8.2	1.4	9.6	7.8	1.8	9.6	5.2	1.1	6.3	4.7	0.5	5.2	4.7	0.5	5.2	4.7	0.5	5.2	4.7	0.5	5.2	4.7	0.5	5.2	4.7	0.5	5.2
No residues	9.2	1.9	11.1	8.1	2.1	10.2	9.4	1.4	10.8	8.2	1.0	9.2	8.2	1.0	9.2	7.6	0.9	8.5	7.6	0.9	8.5	7.6	0.9	8.5	7.6	0.9	8.5
P residues	1.0	0.5	1.5	0.3	0.3	0.6	4.2	0.3	4.5	3.5	0.5	4.0	3.5	0.5	4.0	1.0	0.3	1.3	1.0	0.3	1.3	1.0	0.3	1.3	1.0	0.3	1.3
Effect of P residues																											
Effect of new P (50 lb P/acre) ¹ in the	3.8	0	3.8	2.6	0.6	3.2	2.4	0.1	2.5	-0.3	-0.1	-0.4	1.6	0	1.6	1.6	0	1.6	1.6	0	1.6	1.6	0	1.6	1.6	0	1.6
Absence of residues	0.7	0	0.7	0.5	0.1	0.6	1.0	0	1.0	0.3	0.3	0.6	0.3	0.3	0.6	-0.3	0.3	0.1	-0.3	0.3	0.3	0.6	-0.3	0.3	0.1	-0.3	
Presence of residues																											
¹ 75 lb P/acre Agdell 1961-62.																											
No new P given to soil with	7.3	1.4	8.7	7.1	0.9	8.0	8.0	0.9	8.9	5.8	1.1	6.9	5.8	1.1	6.9	7.2	0.9	8.1	7.2	0.9	8.1	7.2	0.9	8.1	7.2	0.9	8.1
No residues	9.9	1.4	11.3	8.9	1.3	10.2	10.2	1.3	11.5	8.2	1.2	9.4	8.2	1.2	9.4	8.1	1.0	9.1	8.1	1.0	9.1	8.1	1.0	9.1	8.1	1.0	9.1
P residues	2.6	0	2.6	1.8	0.4	2.2	2.2	0.4	2.6	2.4	0.1	2.5	2.4	0.1	2.5	0.9	0.1	1.0	0.9	0.1	1.0	0.9	0.1	1.0	0.9	0.1	1.0
Effect of P residues																											
New P given (50 lb P/acre) to soil with	8.4	1.4	9.8	7.8	1.8	9.6	5.2	1.1	6.3	4.7	0.5	5.2	4.7	0.5	5.2	4.7	0.5	5.2	4.7	0.5	5.2	4.7	0.5	5.2	4.7	0.5	5.2
No residues	10.6	1.9	12.5	10.4	1.1	11.5	11.5	1.1	12.6	9.3	1.6	10.9	9.3	1.6	10.9	8.4	1.3	9.7	8.4	1.3	9.7	8.4	1.3	9.7	8.4	1.3	9.7
P residues	2.2	0.5	2.7	1.2	0	1.2	1.2	0	1.2	2.7	0.6	3.3	2.7	0.6	3.3	0.7	0.2	0.9	0.7	0.2	0.9	0.7	0.2	0.9	0.7	0.2	0.9
Effect of P residues																											
New P given (50 lb P/acre) to soil with	1.1	0	1.1	1.1	2.1	3.2	2.3	0.2	2.5	0.8	-0.1	0.7	0.8	-0.1	0.7	0.5	0.2	0.7	0.5	0.2	0.7	0.5	0.2	0.7	0.5	0.2	0.7
No residues	0.7	0.5	1.2	1.5	-0.2	1.3	1.3	-0.2	1.1	1.1	0.4	1.5	1.1	0.4	1.5	0.3	0.3	0.6	0.3	0.3	0.6	0.3	0.3	0.6	0.3	0.3	0.6
Effect of new P (50 lb P/acre) in the																											
Absence of residues																											
Presence of residues																											

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because these microplots were superimposed on those of 1959–60, some of which had received P. From the old residues intimately mixed with the soil, the potatoes extracted at least twice as much P. At Woburn the potatoes could get more than three times as much P from the starved soil as from the starved soils at Rothamsted, especially in the wet year of 1960. However, much less extra P was taken up from the residues at Woburn. With new P, uptake of P increased because yield increased.

TABLE 21

Effect of P residues and new P on the amount of P in potato tubers grown at Rothamsted and Woburn, 1957–62

	lb P/acre/year					
	Rothamsted			Agdell		
	Exhaustion Land mean 1957 & 1958 P in furrows	Mean 1959 & 1960 P in furrows	Mean 1961 & 1962		P to ploughed in	P
			P to seedbed	P		
No new P given to soil with						
No residues	2.8	3.0	5.6			5.6
P residues	6.0	9.5	9.2			9.2
Effect of P residues	3.2	6.5	3.6			3.6
New P given (50 lb P/acre) ¹ to soil with						
No residues	9.0	7.2	7.0			8.0
P residues	9.6	12.5	12.7			10.3
Effect of residues	0.6	5.3	5.7			2.3
Effect of new P (50 lb P/acre) ¹ in the						
Absence of residues	6.2	4.2	1.4			2.4
Presence of residues	3.6	3.0	3.5			1.1
	Woburn					
	Wheat Site			Barley Site		
	1962			1961		
	1960 P to seedbed	P to seedbed	P ploughed in	1960 P to seedbed	P to seedbed	P ploughed in
No new P given to soil with						
No residues	13.4	8.9	8.7	17.6	9.1	10.3
P residues	15.8	10.4	10.9	17.1	12.3	13.1
Effect of P residues	2.4	1.5	2.2	-0.5	3.2	2.8
New P given (50 lb P/acre) to soil with						
No residues	15.9	11.2	11.0	19.2	11.5	11.6
P residues	21.3	12.6	11.7	22.1	13.1	14.4
Effect of P residues	5.4	1.4	0.7	2.9	1.6	2.8
Effect of new P (50 lb P/acre) in the						
Absence of residues	2.5	2.3	2.3	1.6	2.4	1.3
Presence of residues	5.5	2.2	0.8	5.0	0.9	1.3

¹ 75 lb P/acre Agdell 1961–62.

Sugar beet. Sugar beet took up about the same total P from both the starved soils of the Exhaustion Land and of Agdell during the first period in

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TABLE 22
Effect of P residues and new P on the amount of P in sugar beet grown at Rothamsted and Woburn, 1957-62

	lb P/acre/year											
	Rothamsted				Agdell							
	Exhaustion Land mean 1957 & 1958 P to seedbed				Mean 1959 & 1960 P to seedbed				Mean 1961 & 1962 P ploughed in			
	Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total
No new P given to soil with	6.4	3.1	9.5	5.2	1.8	7.0	8.8	6.5	15.3	8.8	6.5	15.3
No residues	9.0	8.0	17.0	9.4	5.4	14.8	13.2	11.8	25.0	13.2	11.8	25.0
P residues	2.6	4.9	7.5	4.2	3.6	7.8	4.4	5.3	9.7	4.4	5.3	9.7
Effect of P residues												
New P given (50 lb P/acre) ¹ to soil with	10.8	7.8	18.6	10.3	3.5	13.8	11.2	9.8	21.0	12.6	11.2	23.8
No residues	10.0	9.1	19.1	12.9	6.6	19.5	15.9	14.0	29.9	16.2	16.1	32.3
P residues	-0.8	1.3	0.5	2.6	3.1	5.7	4.7	4.2	8.9	3.6	4.9	8.5
Effect of P residues												
Effect of new P (50 lb P/acre) ¹ in the	4.4	4.7	9.1	5.1	1.7	6.8	2.4	3.3	5.7	3.8	4.7	8.5
Absence of residues	1.0	1.1	2.1	3.5	1.2	4.7	2.7	2.2	4.9	3.0	4.3	7.3
Presence of residues												
Woburn												
	Wheat Site 1962				Barley Site 1961				P ploughed in			
	Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total
No new P given to soil with	10.2	9.2	19.4	11.3	9.8	21.1	5.9	3.7	9.6	7.2	3.8	11.0
No residues	13.2	11.8	25.0	12.0	11.3	23.3	9.9	7.8	17.7	8.1	6.7	14.8
P residues	3.0	2.6	5.6	0.7	1.5	2.2	4.0	4.1	8.1	0.9	2.9	3.8
Effect of P residues												
New P given (50 lb P/acre) to soil with	12.8	9.9	22.7	11.1	9.7	20.8	8.6	5.3	13.9	7.8	5.2	13.0
No residues	10.6	12.0	22.6	11.3	12.3	23.6	9.8	8.6	18.4	9.4	8.7	18.1
P residues	-2.2	2.1	-0.1	0.2	2.6	2.8	1.2	3.3	4.5	1.6	3.5	5.1
Effect of P residues												
Effect of new P (50 lb P/acre) in the	2.6	0.7	3.3	-0.2	-0.1	-0.3	2.7	1.6	4.3	0.6	1.4	2.0
Absence of residues	-2.6	0.2	-2.4	-0.7	1.0	0.3	-0.1	0.8	0.7	1.3	2.0	3.3
Presence of residues												

¹ 75 lb P/acre Agdell 1961-62.

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both experiments, and the extra uptake from the residues was 7.5 lb P/acre (Table 22). During the second period on Agdell, 1961–62, uptakes from the starved soils were twice as much as in 1959–60, but the extra uptake from the old residues (9.7 lb P/acre) was only a little greater, so the plants must have taken up either much more native soil P or extra P from the residues of the dressings given in 1959–60. The residues at Woburn supplied much less P (2 to 4 lb/acre) for sugar beet than the residues at Rothamsted. With new P, the crop still took up the same amount of extra P from the residues at Woburn and on Agdell as it did without new P, but not on the Exhaustion Land where, with new P, the uptake from the residues was much less.

Kale and swedes. Table 23 shows the uptakes by both crops from the Exhaustion Land in 1957–58. Kale took up much the same amount of P as sugar beet, except on the enriched soil with new P, where it took up more. With new P, the increase in yield between starved and enriched soils was small, 1 ton/acre increase in 20 tons/acre, and some of the extra uptake from the enriched soil with new P was probably 'luxury' (without a commensurate increase in yield). Swedes took up about 4 lb/acre P from starved soil without new P, about the same amount as potatoes. However, in contrast to potatoes, the swedes took up very much more P from the enriched soil, 16 lb compared to 6 lb by potato tubers.

TABLE 23

Effect of P residues and new P on the amount of P in kale and swedes grown on the Exhaustion Land, Rothamsted, 1957–58

	lb P/acre/year			
	Kale	Swedes		
		Tops	Roots	Total
No new P given to soil with				
No residues	9.6	1.4	3.1	4.5
P residues	19.8	3.2	12.6	15.8
Effect of P residues	10.2	1.8	9.5	11.3
New P added (50 lb P/acre) to soil with				
No residues	17.6	3.4	12.3	15.7
P residues	25.0	3.7	13.0	16.7
Effect of P residues	7.4	0.3	0.7	1.0
Effect of new P (50 lb P/acre) in the				
Absence of residues	8.0	2.0	9.2	11.2
Presence of residues	5.2	0.5	0.4	0.9

Summary of the effects of P residues and new dressings of P fertiliser on P uptake

On any one site, different crops can be compared to see how much P they take up in the presence and absence of residues. From the starved soil without new P on the Exhaustion Land, of the six crops grown, potatoes (3 lb P/acre, possibly 4 lb if tops are included) extracted least P, and kale and

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sugar beet extracted $2\frac{1}{2}$ to 3 times as much. Swedes took up only little more than potatoes, and cereals were intermediate between potatoes and kale. Although the swedes got only a small amount of P from the starved soil, they extracted as much extra P as kale from the soils with residues, swedes, 11 lb P, kale, 10 lb. Sugar beet, which were in the ground longer than swedes, were less efficient than swedes or kale at taking up P from the residues; they took up only 7.5 lb P, but this was twice as much as that taken up by cereals or potatoes. The relative ability to obtain P from starved soils was confirmed for the three crops grown on Agdell and at Woburn. On both these sites, as on the Exhaustion Land, sugar beet took up more P from the residues than did potatoes, which took up the same amount as barley. Thus on the three sites each crop behaved in the same way relative to the others. These residues, because of their age, must have been intimately mixed with the soil and, on any one site, had the same solubility. That different crops take up different amounts of P is presumably related to the ability of their roots to search the soil mass for nutrients and to the length of time they grow. However, there may also be physiological differences that affect the ability of different crops to absorb phosphorus from the soil.

When new P was applied more of this was taken up from starved soils than from enriched soils, except in three tests with potatoes, two at Woburn and one on Agdell. The apparent percentage recoveries, defined as

$$\frac{\text{extra uptake from added P}}{\text{added P}} \times 100,$$

of the freshly added P are small, and only 7 of the 54 values exceeded 10%. Only on the Exhaustion Land, when yields were the same, was the same total P removed from the starved and enriched soils when new P was given. Otherwise the greater yield on soil with residues and new P was always accompanied by the crop taking up more P.

Summary

In these experiments made to value accumulated residues from many dressings of P fertilisers, all crops gave larger yields on enriched soils than on starved soils when new P fertiliser was not given but fresh N and K were.

In the first experiment, on the Exhaustion Land at Rothamsted, four crops (barley, spring wheat, potatoes and swedes) of the six tested gave the same yield on the starved and enriched soils when new P was given and the other two crops (sugar beet and kale) gave almost the same yield. The cereals and potatoes recovered less than 0.5% and the other crops less than 1% per year of the total amount of P applied between 1856 and 1901. These results on the Exhaustion Land would not have justified a policy of deliberately building up residues in soil instead of giving new P each year when needed. However, on Agdell and at Woburn, new P failed to give as large yields of any of the three crops tested on previously starved as on enriched soils. Again the recovery of P from the residues was very small.

Larger yields were always associated with the uptake of more P. Thus, if the crop has to rely on newly applied P, this must be placed where the roots can take it up. Residues, which have been in the soil a long time, are

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intimately mixed with the soil, so the growing roots can get P from anywhere in the cultivated layer. Thus the plant is not prevented from obtaining enough P by poor mixing of a fresh dressing, or poor soil structure resisting root growth to a limited volume of soil.

P residues are probably now accumulating in many well fertilised soils, but how many soils in this country would behave as those on the Exhaustion Land and those on Agdell and at Woburn is not known. More experiments are needed to set limits, on each type of soil, to which P residues must be accumulated before different crops do not respond to new P on enriched soils.

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APPENDIX TABLE 1
Yields of cereals grown on the Exhaustion Land and Agdell at Rothamsted and on the Wheat and Barley Sites at Woburn, 1957-62

Classical Experiment plot	New P dressing to seedbed lb/acre	cwt/acre at 85% dry matter											
		Rothamsted						Agdell					
		Exhaustion Land			Barley grain			Exhaustion Land			Barley straw		
		1957	1958	Mean	Response	1957	1958	Mean	Response	1957	1958	Mean	Response
5	0	20.4	12.1	16.2	—	19.7	26.6	23.2	—	28.4	26.6	27.5	—
	12.5	22.1	20.2	21.2	5.0	19.7	33.5	26.6	3.4	41.6	33.5	37.6	3.4
	25	22.8	24.6	23.7	7.5	22.4	37.2	29.8	6.6	48.6	37.2	42.1	6.6
	50	26.2	29.4	27.8	11.6	21.1	39.6	30.4	7.2	51.2	39.6	46.6	7.2
9	0	25.6	24.0	24.8	—	21.1	38.4	29.8	—	46.6	38.4	42.4	—
	12.5	25.1	25.8	25.4	0.6	22.0	38.1	30.0	0.2	42.4	38.1	45.7	0.2
	25	26.4	27.5	27.0	2.2	25.0	39.3	32.2	2.4	45.7	39.3	48.1	2.4
	50	26.0	29.4	27.7	2.9	22.9	38.1	30.5	0.7	48.1	38.1	51.2	0.7
		Spring wheat grain						Spring wheat straw					
5	0	19.3	18.7	19.0	—	23.0	28.4	25.7	—	28.4	26.6	27.5	—
	12.5	20.3	24.2	22.2	3.2	26.3	41.6	34.0	8.3	41.6	33.5	37.6	8.3
	25	21.2	27.4	24.3	5.3	29.6	48.6	39.1	13.4	48.6	37.2	42.1	13.4
	50	23.2	29.1	26.2	7.2	33.0	51.2	42.1	16.4	51.2	39.6	46.6	16.4
9	0	21.2	23.7	22.4	—	27.3	46.6	37.0	—	46.6	38.4	42.4	—
	12.5	24.1	24.5	24.3	1.9	32.4	42.4	37.4	0.4	42.4	38.1	45.7	0.4
	25	23.8	24.7	24.2	1.8	31.9	45.7	38.8	1.8	45.7	39.3	48.1	1.8
	50	22.6	25.5	24.0	1.6	30.8	48.1	39.4	1.4	48.1	39.6	51.2	1.4
		Spring wheat grain						Spring wheat straw					
		Exhaustion Land			Barley grain			Exhaustion Land			Barley straw		
		1959	1960	Mean	Response	1959	1960	Mean	Response	1959	1960	Mean	Response
5 and 6	0	14.1	10.5	12.3	—	18.6	13.4	16.0	—	18.6	13.4	16.0	—
	12.5	20.6	12.6	16.6	4.3	21.6	14.5	18.0	2.0	21.6	14.5	18.0	2.0
	50	29.4	16.7	23.0	10.7	28.0	17.4	22.7	6.7	28.0	17.4	22.7	6.7
3 and 4	0	31.3	23.0	27.2	—	29.8	22.8	26.3	—	29.8	22.8	26.3	—
	12.5	32.4	23.4	27.9	0.7	29.9	21.8	25.8	-0.5	29.9	21.8	25.8	-0.5
	50	35.0	26.8	30.9	3.7	32.2	25.9	29.0	2.7	32.2	25.9	29.0	2.7
1 and 2	0	23.8	21.8	22.8	—	19.4	25.3	22.4	—	19.4	25.3	22.4	—
	12.5	25.0	22.0	23.5	0.7	21.2	24.1	22.6	0.2	21.2	24.1	22.6	0.2
	50	22.6	24.6	23.6	0.8	20.6	25.7	23.2	0.8	20.6	25.7	23.2	0.8

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Classical Experiment plot	New P dressing to seedbed lb/acre	Woburn Wheat Site						
		Barley grain			Barley straw			
		1960	1962	Mean	1960	1962	Mean	
7 no residues	0	20.0	29.1	24.6	24.0	26.3	25.2	—
	12.5	20.3	27.5	23.9	24.0	24.6	24.3	-0.9
	50	23.2	27.2	25.2	26.9	25.0	26.0	0.8
8 with P residues	0	18.5	26.5	22.5	24.3	24.3	24.3	—
	12.5	18.5	28.3	23.4	24.9	22.0	23.4	-0.9
	50	18.1	24.9	21.5	26.5	21.2	23.8	-0.5
9 with P residues	0	26.9	31.6	29.2	31.5	32.1	31.8	—
	12.5	26.3	29.1	27.8	31.1	29.3	30.2	-1.6
	50	28.3	32.1	30.2	31.5	30.1	30.8	-1.0
		Barley Site						
		Barley grain			Barley straw			
		1960	1961	Mean	1960	1961	Mean	Response
7 no residues	0	16.6	17.9	17.2	19.6	20.9	20.2	—
	12.5	19.3	20.6	20.0	21.0	22.8	21.9	1.7
	50	19.6	21.3	20.4	23.3	24.1	23.7	3.5
8 with P residues	0	23.4	23.4	23.4	24.2	30.2	27.2	—
	12.5	24.3	26.4	25.4	24.8	30.2	27.5	0.3
	50	25.8	23.7	24.8	28.8	35.2	32.0	4.8
9 with P residues	0	22.9	25.3	24.1	24.0	32.5	28.2	—
	12.5	25.8	26.6	26.2	29.5	32.5	31.0	2.8
	50	26.9	27.9	27.4	32.3	36.7	34.5	6.3

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APPENDIX TABLE 2

Yields of potatoes grown on the Exhaustion Land and Agdell at Rothamsted and on the Wheat and Barley Sites at Woburn, 1957-62

Classical Experiment plot	New P dressing ¹ to seedbed lb/acre	Tubers, tons/acre				Response
		Rothamsted Exhaustion Land		Mean	Response	
		1957	1958			
5 no residues	0	5.0	5.2	5.1	—	
	12.5	11.4	11.6	11.5	6.4	
	25	11.8	13.6	12.7	7.6	
	50	12.7	13.3	13.0	7.9	
9 with P residues	0	9.3	7.4	8.4	—	
	12.5	9.6	11.0	10.3	1.9	
	25	11.4	11.0	11.2	2.8	
	50	12.9	13.2	13.0	4.6	
		Agdell				
		1959	1960	Mean	Response	
5 and 6 no residues	0	3.6	6.1	4.8	—	
	12.5	5.8	8.7	7.2	2.4	
	50	7.6	12.6	10.1	5.3	
3 and 4 with P residues	0	7.8	16.0	11.9	—	
	12.5	9.0	17.4	13.2	1.3	
	50	10.2	20.1	15.2	3.3	
1 and 2 with P residues	0	6.8	18.7	12.8	—	
	12.5	8.4	19.6	14.0	1.2	
	50	10.2	22.2	16.2	3.4	
		Woburn Wheat Site				
		1960	1962	Mean	Response	
7 no residues	0	15.1	12.5	13.8	—	
	12.5	15.3	11.9	13.6	-0.2	
	50	16.3	12.8	14.6	0.8	
8 with P residues	0	14.8	11.5	13.2	—	
	12.5	17.0	13.4	15.2	2.0	
	50	16.1	15.5	15.8	2.6	
9 with P residues	0	18.6	14.8	16.7	—	
	12.5	17.7	13.2	15.4	-1.3	
	50	19.7	16.4	18.0	1.3	
		Barley Site				
		1960	1961	Mean	Response	
7 no residues	0	17.3	10.9	14.1	—	
	12.5	16.7	11.3	14.0	-0.1	
	50	19.0	12.7	15.8	1.7	
8 with P residues	0	18.7	12.7	15.7	—	
	12.5	19.4	11.8	15.6	-0.1	
	50	19.8	13.4	16.6	0.9	
9 with P residues	0	17.8	13.7	15.8	—	
	12.5	18.6	12.5	15.6	-0.2	
	50	19.2	14.1	16.6	0.8	

¹ In the furrows before hand planting at Rothamsted, over the flat seedbed before machine planting at Woburn.

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APPENDIX TABLE 3

Yields of sugar from beet grown on the Exhaustion Land and Agdell at Rothamsted and the Wheat and Barley Sites at Woburn, 1957-62

Classical Experiment plot	New P dressing to seedbed lb/acre	Sugar, cwt/acre				Response
		Rothamsted Exhaustion Land		Mean		
		1957	1958			
5 no residues	0	18.3	42.8	30.6	—	
	12.5	27.6	57.5	42.6	12.0	
	25	28.7	61.4	45.0	14.4	
	50	29.4	61.8	45.6	15.0	
9 with P residues	0	29.6	60.8	45.2	—	
	12.5	36.0	56.0	46.0	0.8	
	25	29.0	55.5	42.2	-3.0	
	50	32.5	63.1	47.8	2.6	
		Agdell		Mean	Response	
		1959	1960			
5 and 6 no residues	0	28.1	25.7	26.9	—	
	12.5	31.8	31.8	31.8	4.9	
	50	32.9	43.6	38.2	11.3	
3 and 4 with P residues	0	49.0	43.1	46.0	—	
	12.5	47.7	45.8	46.8	0.8	
	50	47.4	48.2	47.8	1.8	
1 and 2 with P residues	0	32.9	42.8	37.8	—	
	12.5	34.2	44.6	39.4	1.6	
	50	36.3	46.7	41.5	3.7	
		Woburn				
		Wheat Site		Barley Site		
		1962	Response	1961	Response	
7 no residues	0	50.2	—	32.1	—	
	12.5	43.8	-6.4	34.7	2.6	
	50	47.4	-2.8	34.6	2.5	
8 with P residues	0	52.1	—	38.5	—	
	12.5	45.2	-6.9	33.5	-5.0	
	50	45.7	-6.4	31.6	-6.9	
9 with P residues	0	51.0	—	43.0	—	
	12.5	45.5	-5.5	34.5	-8.5	
	50	54.3	3.3	43.6	0.6	

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APPENDIX TABLE 4

Yields of swedes and kale grown on the Exhaustion Land at Rothamsted, 1957-58

Classical Experiment plot	New P dressing to seedbed lb/acre	tons/acre				Response
		1957	1958	Mean		
Swede roots						
5 no residues	0	6.9	10.1	8.5	—	
	12.5	8.4	19.8	14.1	5.6	
	25	11.1	20.8	16.0	7.5	
	50	12.2	23.4	17.8	9.3	
9 with P residues	0	10.4	20.6	15.5	—	
	12.5	11.6	21.5	16.6	1.1	
	25	11.8	20.5	16.2	0.7	
	50	12.2	23.6	17.9	2.4	
Swede tops						
5 no residues	0	1.0	2.5	1.8	—	
	12.5	1.4	4.5	3.0	1.2	
	25	1.8	4.8	3.3	1.5	
	50	1.8	4.7	3.2	1.4	
9 with P residues	0	1.8	4.0	2.9	—	
	12.5	2.0	3.3	2.6	-0.3	
	25	2.2	4.2	3.2	0.3	
	50	2.0	4.1	3.0	0.1	
Kale						
5 no residues	0	13.2	16.3	14.8	—	
	12.5	15.8	22.7	19.2	4.4	
	25	17.4	22.8	20.1	5.3	
	50	19.2	21.0	20.1	5.3	
9 with P residues	0	15.2	23.1	19.2	—	
	12.5	16.5	23.5	20.0	0.8	
	25	17.6	24.9	21.2	2.0	
	50	17.7	25.2	21.4	2.2	