Rothamsted Experimental Station Report for 1969 Part 2

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Ii. A Summary of the Results of Experiments Started by Lawes and Gilbert

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A. E. Johnston (1970) *Ii. A Summary of the Results of Experiments Started by Lawes and Gilbert ;* Rothamsted Experimental Station Report For 1969 Part 2, pp 7 - 21 **- DOI: https://doi.org/10.23637/ERADOC-1-34861**

The Value of Residues from Long-period Manuring at Rothamsted and Woburn
II. A Summary of the Results of Experiments Started by Lawes and Gilbert

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Lawes and Gilbert made many tests of the value of residues of fertilisers and manures accumulated in soil during the long-period of manuring in their experiments, and later, Hall made some further tests. Some of these tests still continue. The results, summarised here, were from modifications made in the following experiments:

Agdell. This 4-course rotation experiment, started in 1848, was described by Warren (1958) and more briefly on page 24.

Barnfield. Various experiments on root crops were made from 1843 to 1959 details of which were given by Warren and Johnston (1962).

Broadbalk. Details of the treatments to the winter wheat were given by Johnston and Garner (1969).

Exhaustion Land. Though mainly cereals have been grown, there was a manurial experiment with potatoes grown continuously from 1876 to 1901. The history of the site was described by Warren and Johnston (1960) and more briefly on page 23.

Hoosfield Continuous Barley. Warren and Johnston (1967) gave the details of the treatments to the barley grown on this site since 1852.

Park Grass. This experiment, started in 1856 to study the manuring of permanent meadow cut twice each year, for hay and later for aftermath, was described by Warren and Johnston (1964).

Permanent Wheat and Barley Experiments at Woburn. The design of these experiments started in 1876 by the Royal Agricultural Society was influenced by Lawes and Gilbert. The experiments have been conducted from Rothamsted since 1926 when the management of the Woburn Farm became the responsibility of the Lawes Agricultural Trust. The history of the sites is described on page 25.

The effect of residues of nitrogen fertilisers

Winter wheat: normal dressings of N. Before 1852 Lawes and Gilbert had showed that a single dressing of inorganic N to the winter wheat on Broadbalk had little residual effect on the following crop of winter wheat (Garner & Dyke, 1969). After 1852 this test, combined with one on the

https://doi.org/10.23637/ERADOC-1-4

residual effects of PKNaMg, was made on plots 17 and 18 and was continued until 1967. Plot 17 received 86 lb N/acre in even years, and PKNaMg fertilisers in odd years, and plot 18 received N in odd years and PKNaMg in even years. Table 1 shows mean yields (Garner & Dyke,

TABLE 1

Effect of the residues of fertiliser N and PKNaMg on winter wheat on Broadbalk, 1852–1967

cwt/acre/year

	Plot and treatment				
	5 PKNaMg annually	17/18 PKNaMg given N residues	10 N annually	7 NPKNaMg annually	17/18 N given PKNaMg residues
Grain	8·9	8·2	12·6	17·7	16·8
Straw	14·0	13·0	20·4	33·2	29·7

1969) on these plots over the whole period 1852–1967. There was no residual effect of N. The yield on plots 17/18 with residual N was only equal to that on plot 5 given PKNaMg annually but no N. However, Table 1 also shows there was a very large residual effect of PKNaMg, because yields on plots 17/18 with N almost equalled those on plot 7, given NPKNaMg each year.

Winter wheat: large dressings of N. Winter wheat grown on plot 16 on Broadbalk during the 1860s showed another interesting residual effect. From 1852 to 1864 annual manuring on plot 16 was NPKNaMg, supplying 172 lb N/acre. The two seasons, 1863 and 1864, both favoured wheat and there was little extra gain from increasing N from 129 to 172 lb. Lawes and Gilbert (1884) stopped applying fertilisers to plot 16 in 1865 but, over the next 19 years, they recorded the yields, which are compared with those of plot 5, given PKNaMg but not N every year in Table 2.

Lawes and Gilbert thought that the very large effect of the residues in 1865, half the direct effect of the 172 lb N in 1863–64, was from ammonia remaining in the soil, for 1864 was the driest year in the then recorded history of the experiment. The 2 to 3 cwt increase in grain yield over the next three years they decided was caused by extra nitrogen released by mineralisation of the larger plant residues in the soil of plot 16 than in plot 5. After 1868, the readily mineralisable N had gone and yields were no better than those on plot 5.

Barley after turnips and swedes. After turnips and swedes had been grown on Barnfield for ten years, Lawes and Gilbert grew barley without manure in 1853, 1854 and 1855. The yields in Table 3 from Lawes and Gilbert (1857) confirmed their often repeated statement that good yields required 'available nitrogen within the soil'. Residues from the NPK given to the turnips gave a small (1·5 cwt) extra yield of grain in each of

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TABLE 2

Direct and residual effect of 172 lb fertiliser N on winter wheat on Broadbalk, 1863–83

Grain, cwt/acre/year

	Plot and treatment		
	5	16	
Year	PKNaMg annually	NPKNaMg annually including 172 lb N/acre	Effect of 172 lb N
1863	11·1	31·1	20·0
1864	9·3	28·8	19·5
	PKNaMg annually	Unmanured	Effect of N residues
1865	7·7	17·8	10·1
1866	7·2	9·5	2·3
1867	4·9	7·7	2·8
1868	9·9	12·8	2·9
Period			
1869–73	8·4	8·7	0·3
1874–78	6·9	6·7	−0·2
1879–83	7·6	6·9	−0·7

the three years. How small was emphasised in 1854 when, on part of the 'Valley' plots with the same P and K residues as the main plots, 82 lb N/acre was given, which increased yield by 17·8 cwt grain.

TABLE 3

Effect of residues from fertilisers given to roots on the yield of barley on Barnfield, 1853–55

Grain, cwt/acre/year

	Treatment to turnips 1845–52			Treatment to barley 82 lb N/acre in 1854 only
	Unmanured	PK	NPK total N 263 lb/acre	
1853	10·2	10·6	11·8	—
1854	9·0	9·6	10·4	26·8
1855	9·1	9·6	10·3	12·7

Barley after potatoes. From 1902 to 1940 unmanured cereals followed the potato experiment on the Exhaustion Land. Table 4 shows the yields of cereals, which were measured on all plots only in the first three years and again from 1917 to 1922. Between 1856 and 1901 annual dressings of 86 lb N/acre were given 44 times. In 1902, yield after potatoes manured with either N or NPK was much larger than after potatoes unmanured or given only PK. However, the smaller crops on the N only than on the NPK plots left smaller residues and the effect of these disappeared in two years. On the NPK plots mineralisation of N gave small increases in yield for some years but the effect disappeared by 1919–22.

https://doi.org/10.23637/ERADOC-1-4

TABLE 4

Effect of residues from fertiliser dressings on the yield of unmanured cereals on the Exhaustion Land, 1902–22

Grain, cwt/acre/year

		Treatment 1856 to 1901				
Year	Crop	Unmanured	N	P	PK	NPK
1902	Barley	16·6	29·4	16·9	12·0	31·6
1903	Barley	6·0	9·1	6·4	6·2	13·2
1904	Oats	10·8	11·2	10·9	9·9	15·3
1917	Barley	3·2	3·0	3·0	3·2	5·5
1918	Barley	4·5	6·6	6·9	7·1	9·6
1919	Barley	2·8	3·6	4·2	5·1	5·0
1921[1]	Wheat	8·1	11·6	15·7	15·2	14·4
1922	Barley	6·4	7·8	7·5	7·0	7·8

[1] The 1920 crop failed.

The effect of residues from potassium fertilisers

Residues of potassium manures were measured in four experiments.

Swedes. In the experiment with swedes on Barnfield, K was not applied between 1861 and 1870 to plots given K between 1845 and 1860. Table 5 shows mean yields for four periods for the crops given N as ammonium sulphate.

TABLE 5

Direct and residual effect of potassium fertilisers on turnips, and swedes, Barnfield, 1845–70

Roots, tons/acre/year

		Plot and treatment		
Crop	Period	4A NPKNaMg	5A NP	3A or 8A Unmanured
Turnips	1845–48	9·8	9·9	1·4
Swedes	1849–52	9·4	8·7	3·8
Swedes	1856–58[1]	6·5	5·4	1·7
Swedes	1861–70	NP (KNaMg residues) 5·0	NP (no K) 4·0	Unmanured 1·2

[1] The crops of 1859 and 1860 failed.

At first (1845–48) there was no response to K. Later, however, because of the gradual depletion of soil K where none was given as fertiliser, there was a response and giving fresh K increased yield by 1·1 tons/acre/year between 1856 and 1858. On plot 4A the mean annual dressing of 100 lb K/acre as fertiliser between 1845 and 1860 was more than that removed in the tops and roots; the residue that accumulated in the soil during this period maintained a yield of 1·0 ton roots/acre more than on plot 5A during the next ten years, 1861–70.

https://doi.org/10.23637/ERADOC-1-4

Mangolds and sugar beet. The residual effect of K fertilisers on Barnfield was confirmed between 1903 and 1959 with both mangolds and sugar beet when these crops were given N as ammonium sulphate. Strip 7, which had had K whenever it was applied to strips 4 and 6 until 1902, was manured with PNaMg only from 1903. The amount of Na and Mg was equal to that given on strip 4. Yields, of both crops (Table 6) given by K residues, from fertiliser dressings applied before 1902, were equal to those given by fresh dressings of K throughout the last 56 years of the experiment.

TABLE 6

Effect of residues from potassium fertilisers on mangolds and sugar beet on Barnfield, 1904–59

Roots, tons/acre/year

		Plot and treatment		
		6A NPK	4A NPKNaMg	7A NPNaMg (K residues)
Crop	Period			
Mangolds	1904–40	14·5	15·5	16·1
Mangolds	1941–59	11·7	12·8	12·2
Sugar beet	1946–59	6·6	7·2	7·2

Potatoes. Table 7 shows potato yields during three periods of the experiment on the Exhaustion Land; plots 9 (P only) and 10 (PKNaMg) were sited on plot 1 (PKNaMg) of the preceding wheat experiment (1856–1874).

TABLE 7

Effect of residues from potassium fertilisers on potatoes on the Exhaustion Land, 1876–1901

Tubers, tons/acre/year

	Plot and treatment		
	1 Unmanured	10 PKNaMg	9 P (K residues)
Period			
1876–81	2·3	4·1	4·0
1882–87	1·7	3·4	3·4
1888–1901	0·8	2·2	1·9

Unfortunately N was not given to these plots, but the K residues accumulated during the wheat experiment gave as good a yield of potatoes as did fresh dressings of K during the first twelve years, though yields decreased later.

Grass cut for hay. On Park Grass the early experiments on the value of residues of manurial dressings were not complicated by major changes in botanical composition, as were many of the comparisons of manurial treatment on yield. Plots 9 and 10 received the same manures (NPKNaMg) between 1856 and 1861, except that plot 10 also got sawdust, which had

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no effect on the yield of hay. Plot 10 received no more K after 1861, or sawdust after 1862. Table 8 shows the yields on these two plots and on plot 4/2 (NP).

TABLE 8

Direct and residual effect of potassium fertilisers on the yield of hay on Park Grass, 1856–75

cwt/acre/year of hay[1]

	Plot and treatment		
	9 NPKNaMg	10 NPKNaMg	4/2 NP
1856–61	56·7	55·6	43·9[2]
	NPKNaMg	NPNaMg (K residues)	NP (no K)
1862–66	48·0	47·8	36·0
1867–75	48·9	39·1	30·0
1920–59[3]	37·2	24·2	16·4

[1] Yields 1856–76 from Lawes & Gilbert, 1880. Yields 1920–59 from Warren & Johnston, 1964.
[2] 1859–61 only.
[3] Unlimed halves of each plot.

Yields with NP only (plot 4/2) decreased during each of the periods. During the first 6 years, 1856–61, there was a response to fresh K of 12 cwt hay/acre. During the next 5 years, 1862–66, the residues of K accumulated on plot 10 between 1856 and 1861, maintained as good a yield as was given by fresh dressings of K. Then, in the 9 years between 1867 and 1875, the decreasing K residues gave yields intermediate between those on plot 4/2, always without K, and on plot 9, always given K. From their analyses Lawes and Gilbert concluded that there would have been about 400 lb K remaining in the soil of plot 10 in 1862 from the 870 lb applied between 1856 and 1861. Using the uptake on plot 4/2 as a measure of the K released from the soil, they also calculated that during the next 14 years the extra crops recovered half of this residue of 400 lb K.

The large differences in yield on plots 4/2, 9 and 10 for the period 1920 to 1959 (Table 8) are probably not simply the effect of K, but reflect the interaction of manuring and differential soil acidity, which had developed on the plots, on the plant species able to tolerate each set of conditions.

The combined effect of residues from P and K fertilisers

Unfortunately no experiment made in the early period at Rothamsted tested the effects of P residues only. In some experiments Lawes and Gilbert simply stopped applying both P and K fertilisers to plots previously given them, and measured the combined effect of PK residues.

Winter wheat. The residual effects of small dressings of P and K were shown by modifying the treatments to plots 10A and 10B on Broadbalk. Both plots received PK in 1844. For the next 39 years, plot 10A had 86 lb N

https://doi.org/10.23637/ERADOC-1-4

annually, whereas 10B had two more dressings of P and K (in 1848 and 1850) followed by 33 years with 86 lb N annually. Table 9 (from Lawes & Gilbert, 1884) gives yields for four 8-year periods.

TABLE 9

Effect of PK residues on winter wheat on Broadbalk, 1852–83

Grain, cwt/acre/year

Plot	10A	10B	
Treatment	PK in 1844 39 years N only	PK in 1844, 1848, & 1850 then 33 years N only	Effect of PK residues (10B minus 10A)
Period			
1852–59	11·8	14·2	2·4
1860–67	12·4	14·1	1·7
1868–75	9·8	10·4	0·6
1876–83	8·5	9·4	0·9

The residues from 60 lb P and 240 lb K produced, when N was also given, a mean annual yield increase of 2·4 and 1·7 cwt grain in the first and second 8-year periods, but after that their effects diminished rapidly.

Barley. Beginning in 1941 the barley on the Exhaustion Land was manured annually with N. Yields were taken from 1949, and averages for the first 5 years with N at 56 lb N/acre are in Table 10. Even after 50 years the residues of the P and K applied between 1856 and 1901 gave, when N was given, an extra 9 cwt grain. That these residues had such a good effect after such a long time is, no doubt, because N was not given between 1901 and 1940 and the yields of the cereals grown, and the uptakes of P and K, were small. In this experiment, though the effect as measured was that of P plus K, Warren (1956) concluded from analyses of the crops that the increase in yield was mainly from the P residues.

TABLE 10

Effect of PK residues on barley when N was given on the Exhaustion Land, 1949–53

cwt/acre/year

	Treatment (other than N) 1856–1901		
	No P no K	P[1]	PK
Grain	10·8	18·4	19·7
Straw	12·7	19·1	20·6

[1] PK, 1856–75; P, 1876–1901.

Winter wheat and barley at Woburn. In 1959 and 1960 these two crops, given basal N, were grown on every plot of the Permanent Wheat and Barley Sites at Woburn, last manured with P and K in 1926. Table 11 shows yields, as averages of all plots with appropriate treatments.

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TABLE 11

Effect of residues of PK fertilisers and FYM on wheat and barley on the Woburn Permanent Wheat and Barley Sites, 1959–60

Grain, cwt/acre/year

	Treatments applied 1877–1926		
	No P no K	PK	FYM
Winter wheat			
Wheat Site	16·9	18·8	24·8
Barley Site	24·9	24·3	28·0
Barley			
Wheat Site	19·6	24·1	24·0
Barley Site	18·3	21·5	23·8

Wheat yielded better on the Barley Site than on the Wheat Site and barley better on the Wheat Site than on the Barley Site. To what extent this reflected differences in disease or fertility between the two sites is not known. In seven of the eight comparisons, yields were increased by residues of PK accumulated between 1877 and 1926 from fertiliser or FYM.

Beans and potatoes. These two crops, grown on Agdell in 1956 and 1957 respectively, valued the combined effect of the accumulated residues of PK fertiliser given once every 4 years during the four-course rotation experiment and last applied in 1948. Table 12 gives the yields of field beans, grown without added N, and of potatoes, given basal N.

TABLE 12

Effect of residues of PK fertilisers on beans and potatoes on Agdell 1956 and 1957

	Fertiliser treatment and rotation 1848–1951					
	Unmanured		PK		NPK	
	Fallow	Clover	Fallow	Clover	Fallow	Clover
1956 Beans						
Grain cwt/acre	8·5	5·2	26·2	20·0	18·2	19·2
1957 Potatoes						
Total tubers tons/acre	4·4	3·0	14·4	8·6	15·5	14·1

The yields of both beans and potatoes from PK residues were as good as from many well manured crops on Rothamsted Farm. The mean increases from the combined effects of P and K were 14 cwt/acre bean grain and 8·5 tons/acre of potatoes. In five of the six comparisons, yields were smaller on plots where clover was grown in the rotation while other plots were fallowed, because P and K were removed in the clover and less was left to accumulate in the soil.

Warren (1958) showed that the two crops differed little in the amount of P they took from the starved or from the enriched soil, but the potatoes took up more K than the beans from the starved soil and much more K from the enriched soil (Table 13).

https://doi.org/10.23637/ERADOC-1-4

TABLE 13

Effect of PK residues on the amount of P and K removed in the beans and potatoes grown on Agdell, 1956 and 1957

	Fertiliser treatment and rotation, 1848–1951					
	Unmanured		PK		NPK	
	Fallow	Clover	Fallow	Clover	Fallow	Clover
	Uptake of P lb/acre					
Bean grain	4	2	14	10	11	11
Potato tubers	3	2	13	7	13	12
	Extra P from residues lb/acre					
Bean grain	—	—	10	8	7	9
Potato tubers	—	—	10	5	10	10
	Uptake of K lb/acre					
Bean grain	9	5	32	22	23	23
Potato tubers	24	18	110	54	119	96
	Extra K from residues lb/acre					
Bean grain	—	—	23	17	14	18
Potato tubers	—	—	86	36	95	78

The effect of residues of FYM

FYM was the standard source of plant nutrients when Lawes and Gilbert started their experiments on the effects of the 'new' inorganic fertilisers. Yields on unmanured soil were compared with those on soils dressed with fertilisers and FYM. The dressing of FYM was 14 tons/acre, and many analyses showed this amount contained, on average, 200 lb total N. The N supplied by this dressing of FYM, when given each year in the Classical Experiments has increased the total soil N much more than where N was given as fertilisers. Lawes and Gilbert (1895) concluded that N from FYM residues gave three-quarters of the extra yield of barley between 1872 and 1891 on plots given FYM between 1852 and 1871. The conclusion that N from FYM residues gives worthwhile increases in yield for some years is supported by the results of the next three experiments below. However, FYM also supplies P and K and the effects of residues of FYM may therefore reflect any combination of N, P and K as discussed later.

Grass cut for hay. The first experiment on the value of residues of FYM was made on Park Grass. The manure, applied annually at 14 tons/acre to this permanent pasture, did not readily decompose and Lawes and Gilbert (1880) noted that the sward deteriorated with this treatment. Annual dressings of FYM were stopped in 1863 after 8 years, but yields of hay (Table 14) continued to be taken.

During the 6 years 1864–69 the residues gave yields as large as fresh dressings did during the previous 8 years. Their effect diminished during the next period, but they continued to increase yields by a small but consistent amount even between 1920 and 1959.

https://doi.org/10.23637/ERADOC-1-4

TABLE 14

The direct and residual effect of farmyard manure on yields of hay in the Park Grass Experiment, 1856–1959

cwt/acre/year of hay

	Plot and treatment		
Period	3 Unmanured	2 FYM	Effect of fresh dressing
1856–63	23·8	42·9	19·1
	Unmanured	Residues of 112 tons/acre FYM	Effect of residues
1864–69	24·1	43·3	19·2
1870–75	15·1	22·5	7·4
1920–59	8·2	9·4	1·2

Potatoes. At the start of the potato experiment (1876–1901) on the Exhaustion Land, plot 2 was dressed annually with FYM for the first 6 years (1876–81), after when it was unmanured. The FYM residues on this plot gave better yields than the unmanured plot until the end of the experiment (Table 15), and during the first 6 years gave half the yield increase that fresh dressings had given between 1876–81.

TABLE 15

The direct and residual effect of farmyard manure on yields of potatoes on the Exhaustion Land, 1876–1901

Tubers, tons/acre/year

	Plot and treatment		
Period	1 Unmanured	2 FYM each year	Effect of fresh dressing
1876–81	2·3	5·2	2·9
	Unmanured	Residues of 84 tons FYM	Effect of residues
1882–87	1·7	3·0	1·3
1888–1901	0·8	1·5	0·7

Barley. Effects of residues of FYM given to the potatoes on the Exhaustion Land were measured in the following cereal, and are compared in Table 16 with the effects of residues of PK fertilisers. The FYM residues increased yields greatly during the first 3 years but it is not possible to show when the effects declined because the fertiliser plots were used for an experiment on legumes between 1905 and 1911. However by 1917 the FYM plots were yielding no better than the PK plots. The yields, between 1902 and 1904, given by the NPK residues, discussed previously, and FYM residues are compared in Table 17.

https://doi.org/10.23637/ERADOC-1-4

TABLE 16

Comparison of the effects of the residues of farmyard manure and PK fertilisers on yields of cereals on the Exhaustion Land, 1902–22

Grain, cwt/acre/year

Treatment 1856–1901	1902 Barley	1903 Barley	1904 Oats	1917 Barley	1918 Barley	1919 Barley	1921 Wheat	1922 Barley
PK	12·0	6·2	9·9	3·2	7·1	5·1	15·2	7·0
FYM[1]	34·2	22·6	26·8	3·5	7·9	5·4	14·1	9·6
FYM[2]	34·9	21·6	29·6	4·7	7·7	6·0	15·7	9·7

[1] FYM + P, 1876–82; FYM, 1883–1901.
[2] FYM + NP, 1876–81; FYM + P, 1882; FYM, 1883–1901.

TABLE 17

Comparison of the effects of the residues of farmyard manure and NPK fertilisers on the yields of cereals on the Exhaustion Land, 1902–04

Grain, cwt/acre/year

		Treatment 1856–1901			Effect of residues of	
		PK	NPK	FYM	NPK	FYM
1902	Barley	12·0	31·6	34·6	19·6	22·6
1903	Barley	6·2	13·2	22·1	7·0	15·9
1904	Oats	9·9	15·3	28·2	5·4	18·3

In 1902 the FYM residues only gave 3 cwt more grain than the NPK residues but in both 1903 and 1904 they gave much more because extra nitrogen from the FYM was mineralised.

The effect of P and K in FYM residues

Barley. In the three experiments described in the preceding section most of the effect of the FYM residues was from nitrogen. On the Exhaustion Land, barley yields with FYM residues were larger than with PK residues between 1902 and 1904 but not between 1917 and 1922. After 1940, nitrogen fertiliser was applied to all plots and yields between 1949 and 1953 with FYM residues were only very slightly larger than with the residues of PK fertilisers (Table 18).

TABLE 18

Comparison of the effects of old residues of farmyard manure and PK fertilisers on barley given nitrogen of the Exhaustion Land, 1949–53

cwt/acre/year
Treatment
56 lb N/acre 1949–53

	PK 1856–1901	FYM 1876–1901
Grain	19·7	20·5
Straw	20·6	22·4

https://doi.org/10.23637/ERADOC-1-4

The P and K of the FYM residues must have been as 'available' as that of the fertiliser residues. Yields in Table 19 show that, as the experiment has continued, the FYM residues have given better yields than the PK residues.

TABLE 19

Comparison of the effects of old residues of farmyard manure and PK fertilisers on barley given nitrogen on the Exhaustion Land, 1949–68

Grain, cwt/acre/year

	N each year plus			
Period	no P no K	Residues of FYM given 1876–1901	Residues of P and K fertilisers 1856–1901	FYM minus PK residues
1949–53	10·8	20·5	19·7	0·8
1954–55	14·3	27·6	25·4	2·2
1961–62	15·4	24·6	21·4	3·2
1964–65	12·4	32·8	28·3	4·5
1966–68[1]	11·1	32·4	26·4	6·0

[1] Not 1967 when the site was fallowed.

The N and PK effects of FYM residues were also shown in the Hoosfield Continuous Barley Experiment. Plot 7 recieved the standard dressing of FYM (14 tons/acre) for the first 20 years of the experiment, then the plot was halved, and one-half (plot 7/1) remained unmanured from 1872 to 1967. Table 20 gives yields for each decade; between 1917 and 1966 mainly Plumage Archer was grown.

TABLE 20

Effect of residues of farmyard manure on barley on the Hoosfield Continuous Barley Experiment, 1872–1961

Grain, cwt/acre/year

Plot treatment	1872 –81	1882 –91	1892 –1901	1902 –11	1912 –21[1]	1922 –31	1932 –41[2]	1942 –51[3]	1952 –61[4]
1/0 unmanured	6·8	6·2	5·3	5·2	6·5	3·7	6·9	9·3	7·4
7/1 FYM residues	17·4	13·0	10·6	9·7	11·0	7·0	13·4	15·1	11·7
Increase due to FYM residues	10·6	6·8	5·3	4·5	4·5	3·3	6·5	5·8	4·3

[1] Omitting 1912. [2] Omitting 1933. [3] Omitting 1943. [4] Omitting 1953.

Warren (1956) showed that extra P and K was responsible for some of this extra yield with old FYM residues but that the limiting factor was the slow release of N from the organic matter. He calculated that between 1872 and 1956 the average amount of N that was mineralised produced an extra 3 cwt grain and 4 cwt straw each year containing about 6 lb N.

When Plumage Archer and Maris Badger were grown side by side on each plot between 1964 and 1966, yields of Maris Badger were not in-

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creased by the small amounts of extra N available on plot 7/1 (Warren & Johnston, 1967):

Barley, Hoosfield, 1964–66

Grain, cwt/acre/year

	Unmanured	FYM residues	Effect of residues
Plumage Archer	8·2	13·3	5·1
Maris Badger	8·3	8·6	0·3

This emphasises that the value of residues for new varieties of crop must be examined, for the larger yields these make possible are attained only with large amounts of nutrients.

In 1968 the Hoosfield experiment was modified and four amounts of N (0, 43, 86, 129 lb N/acre as 'Nitro-Chalk') were tested with Maris Badger. With the larger amounts of N yields on plot 7/1 were as good as those on the old plot 4/A, which received N as ammonium sulphate and PKNaMg annually since 1852, suggesting that Maris Badger's poor performance on residues alone in 1964–66 was solely because of the small supply of N:

Barley, Hoosfield, 1968

Grain, cwt/acre

		N lb/acre in 1968[1]			
Plot	Treatment	0	43	86	129
4/A	PK annually since 1852	16·1	31·3	37·3	34·2
7/1	Unmanured since 1872 (280 tons FYM 1852–71)	10·5	28·6	39·1	36·8

[1] Plot 7/1 got 57, 115 and 172 lb N instead of 43, 86 and 129 lb N.

Without fresh N in 1968, the yield on the PK plot exceeded that on the plot with very old FYM residues, probably because of the extra N mineralised from the larger root and stubble residues ploughed in on this plot. Now that N is being given, it will be interesting to see how long the P and K residues from the FYM applied 100 years ago continue to give good yields.

The effect of residues of rape cake

Lawes and Gilbert used rape cake to supply both organic matter and nutrients, mainly N, and compared its effects with those of FYM and inorganic fertilisers. It was applied at 2000 lb/acre to winter wheat and root crops and 1000 lb/acre to barley; the larger amount on average supplied 100 lb N, 20 lb P and 20 lb K. The unmanured barley taken on Barnfield in 1853–55 measured the effect of the residues of rape cake applied from 1845 to 1852 (Table 21). The rape cake residues increased yield more than did the residues of inorganic NPK fertilisers (Table 3).

During the war of 1914–18 rape cake was unobtainable and after the existing stocks were exhausted in 1916 none was applied again until 1921. Table 22 shows the yields, for three 4-year periods, with fresh dressings and residues, on Broadbalk, Hoosfield and Barnfield.

https://doi.org/10.23637/ERADOC-1-4

TABLE 21

Effect of residues of rape cake on barley on Barnfield, 1853–55

Grain, cwt/acre/year

	Treatment to turnips 1845–52		
	Unmanured	PK + rape cake total N 568 lb	NPK + rape cake total N 831 lb
1853	10·2	14·7	14·9
1854	9·0	12·4	11·9
1855	9·1	11·6	11·4

TABLE 22

The direct and residual effects of rape cake on cereals and roots at Rothamsted, 1913–24

	1913–16			1917–20			1921–24		
	None	With fresh dressing of rape cake	Effect of fresh dressing	None	With residues of rape cake	Effect of residues	None	With fresh dressing of rape cake	Effect of fresh dressing
Hoosfield barley Grain, cwt/acre	7·7	20·2	12·5	4·4	6·0	1·6	3·8	11·8	8·0
Broadbalk wheat Grain, cwt/acre	5·8	10·5	4·7	5·1	7·2	2·1	3·2	6·4	3·2
Barnfield mangolds Roots, tons/acre	2·2	6·4	4·4	2·8	7·5	4·7	2·8	6·0	3·2
Tops, tons/acre	0·9	2·8	1·9	0·7	1·9	1·2	1·2	2·4	1·2

The yield of barley was much increased by fresh dressings of rape cake but the residues gave little increase in grain yield. For winter wheat, the residues gave about half the increase given by the fresh dressings and, for mangolds, both tops and roots, the residues gave yields equal to those given by fresh dressings. These results emphasise that the residues of any particular fertiliser may have a quite different effect on different crops, probably depending on the rate and time N is released, and possibly on the root system of the crop. Barley, with a short growing season, was probably unable to use N mineralised after early summer but, provided this later-mineralised N was not leached from the soil, winter wheat could use it. The long growing season of the mangolds helped them to use all the N mineralised during the growing season.

Summary

These experiments showed that soils containing residues of previous manures gave better yields than soils without such residues. The size of the effect differed with different nutrients and different crops, and even with different varieties of one crop.

A single dressing of 86 lb N/acre applied to winter wheat grown annually has no residual effect. However, large dressings of ammonium salts can leave enough residue in the soil, especially after a very dry year, to benefit a succeeding crop, when this is autumn-sown. There is an important

https://doi.org/10.23637/ERADOC-1-4

indirect effect of fertiliser N when used for many years with other nutrients, the larger crops it produces means more stubble and roots are left in the soil, the extra N mineralised from these residues increases yields of future crops. This effect, though small compared with that of fresh N, usually lasted for up to three years with cereals.

The N from residues of recently applied FYM often increased yields for several years; also residues of old FYM release enough N to give small but consistent increases in yield.

Because the N effect of old residues of FYM are always much smaller than the effects of new fertiliser N dressings, the experiments made between 1957 and 1962 tested only the P and K residues from FYM.

None of the experiments made before 1957 showed the effects of P residues only. On the Rothamsted soil the effects of K residues were sometimes large, giving yields for several years as large as those given by fresh dressings. The results of these experiments do not show whether the same yield can be obtained by applying fresh dressings of P and K to starved and to enriched soils.

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