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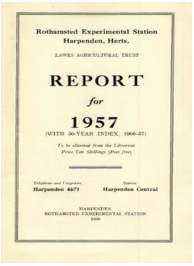

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THE RESIDUAL EFFECTS OF THE MANURIAL AND CROPPING TREATMENTS IN THE AGDELL ROTATION EXPERIMENT

By

R. G. Warren

The Agdell Rotation Experiment was started by Lawes and Gilbert in 1848 and tested two crop rotations and three manurial treatments.

The two cropping schemes were both four-course rotations, one of which was the Norfolk four-course with swedes, barley, clover (or beans) and wheat; the other rotation had the same root and cereal crops, but a fallow replaced the leguminous crop of the Norfolk four-course rotation. The two rotations, side by side, occupied 2½ acres in Agdell Field, on a soil which is one of the heaviest on the Rothamsted farm. The clover, undersown in the barley, failed in some winters, and beans were then sown as a substitute. Although in the early years of the experiment there were more bean than clover crops, the ratio for the whole period was two crops of clover to one of beans.

The manurial treatments were O, P (which was changed to PK in 1884) and NPK; these were put down as three strips across the two rotations. The manures were given once in 4 years and applied to the swede crop only. Part of the nitrogen was supplied as ammonium salts and the remainder as rape cake. Until 1912 the inorganic nitrogen fertilizer consisted of equal parts of ammonium chloride and ammonium sulphate, but afterwards it was given entirely as sulphate. Rape cake was replaced by castor meal in 1940 and in later years. Phosphorus and potassium were supplied as

Table 1

Agdell rotation experiment 1848–1951

Average dressings of manures, cwt./acre, applied every fourth year

Manure	Treatment PK	Treatment NPK
Ammonium sulphate	—	2
Rape cake (or castor meal)	—	18
Superphosphate	4	4
Potassium sulphate	3	3½

Supplementary minerals, sodium sulphate at 100 lb./acre and magnesium sulphate at 200 lb./acre, were given whenever potassium sulphate was applied.

superphosphate and potassium sulphate. Throughout the experiment the amount of nitrogen given in each form remained unchanged, but the dressings of superphosphate were increased in 1904

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from 3½ to 4½ cwt./acre and those for potassium sulphate from 2¾ to 4½ cwt./acre in 1896. The average dressings of the manures are given in Table 1, in which all the inorganic nitrogen has been expressed as ammonium sulphate.

In addition to the comparisons of three manurial treatments on two rotations, Lawes and Gilbert included a test of management when roots were grown. On half of each plot the roots and leaves were carted off; on the other half the produce was eaten on the land by sheep, or, if the weather was unsuitable, the leaves and the roots (after slicing) were spread over the ground. This test was continued until 1900, but in later years the crop was removed from the whole of each of the six plots.

Summary of the Results of the Agdell Experiment

The experiment was continued until 1951, but by then the crops on the NPK plots were affected by soil acidity. The swede crops were generally ruined by clubroot, which first appeared on the acid plots but spread to the other plots. Table 2 gives the average yields of the crops for the first eighteen courses (1848–1919) before the disturbance from soil acidity became serious.

Table 2

Average yields, Agdell Field, 1848–1919

	No manure		PK		NPK	
	Fallow rotation	Clover rotation	Fallow rotation	Clover rotation	Fallow rotation	Clover rotation
Swedes, tons ...	1·7	0·6	8·8	9·6	18·0	15·9
Barley, cwt. ...	11·4	10·8	12·0	12·0	16·4	18·4
Beans, cwt. ...	—	7·7	—	10·7	—	13·1
Clover hay, cwt.	—	30·7	—	58·6	—	60·2
Wheat, cwt. ...	13·8	12·8	16·3	17·7	16·9	17·8

The average results for the eighteen courses show that the two rotations gave similar yields of roots and cereals and that the main advantage of the clover rotation was the extra produce as beans or clover.

In contrast with the effect of crop rotation on yields, there were large responses to the manurial treatments. Nitrogen increased the yields of swedes by 6–9 tons/acre, and on the following crop of barley the residues of the nitrogen manures gave 4–6 cwt./acre more grain; there was, however, no residual effect on wheat, which was the last crop after the application of the nitrogen manures. The PK fertilizer treatment also gave large increases in yields; the increases per acre were for swedes 7–9 tons, clover 30 cwt., beans 3 cwt. and wheat 2·5–5 cwt.

Except for the period of the fed and carted treatments of the swede crop, the whole of each crop in the Agdell Rotation Experiment was removed from the land. While there was no evidence from the crop yields of any accumulation of residues of the nitrogen manures, the wheat crops on the unmanured and PK plots showed that there were residues of the PK fertilizers at the end of the manuring cycle. The response of the wheat crops to residues of these fertilizers provided no estimates of the amounts of phosphorus and

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potassium that had accumulated over the whole period of the experiment, nor of the ability of the residues to supply adequate amounts of these nutrients to crops which have higher requirements than wheat.

Effects of the Accumulated Residues of PK Fertilizers

After the conclusion of the Rotation Experiment in 1951 the field was fallowed for 1 year and was then cropped with cereals till 1955. The cereals received only a uniform dressing of nitrogen. During this period a pH survey of the experimental site was made. Serious soil acidity (i.e., pH 5·0–5·5) was found only on the NPK plots, but small areas at the ends of the PK plots which adjoined the NPK plots were either slightly acid or devoid of calcium carbonate. The soils of the remainder of the PK plots and the whole of the unmanured plots contained 2–3 per cent $CaCO_3$. To correct the soil acidity, differential chalk dressings (with a maximum of 5 tons $CaCO_3$/acre for the most acid areas) were applied in the winter of 1953–54. After an interval of 2 years beans and potatoes were grown in successive years to measure the combined effects of the residues of the PK fertilizers applied during the years of the Rotation Experiment. The potatoes received a uniform dressing of nitrogen, but none was given to the beans. The yields were:

Table 3

Effects of the accumulated residues of fertilizers applied in the Agdell rotation experiment

Fertilizer treatment (1848–1951) ...	None		PK		NPK	
Rotation	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
Percentage ware (1½-inch riddle) ...	91	70	95	92	94	92

Good crops of both beans (with yields up to 26 cwt. grain/acre in 1956) and potatoes (up to 15·5 tons/acre in 1957) were grown on the residues of previous manuring. The highest yields were equal to those obtained on other fields of the Rothamsted Farm where 0·6 cwt. P_2O_5 and 1·2 cwt. K_2O/acre was applied to beans and 1·0 cwt. N, 1·0 cwt. P_2O_5 and 1·2 cwt. K_2O together with 12 tons farmyard manure/acre was given to potatoes. Both crops on Agdell showed large increases in yield due to the residues of phosphorus and potassium in the soils of the PK and NPK plots. For beans the average increase was 14 cwt. of grain/acre, and for potatoes 8·5 tons of tubers/acre. These increases are the combined effects of phosphorus and potassium residues, but the design of the original experiment does not make it possible to separate the effects of the two nutrients. In seven of the eight comparisons between the rotation with fallow and the rotation with clover the latter gave lower yields in the residual years. Even on the unmanured plot, the extra crops (taken as clover or beans) on the clover section have further ex-

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hausted the levels of phosphorus and potassium in the soil, which were already very low. In addition to lowering the yields of beans and potatoes by 3 cwt. and 1 ton/acre respectively, the further soil exhaustion caused by the clover crops reduced the proportion of ware potatoes from 90 to 70 per cent. An indication of the cause of the large increase in the proportion of small tubers is given by the phosphorus and potassium composition of the tubers from the fallow and clover sections. The percentages of potassium in the potatoes from the two sections were almost identical, but the crop from the clover section had a much lower phosphorus content. The values were:

	Percentage in dry matter	
	P	K
Unmanured plot:		
Fallow rotation	0·149	1·26
Clover rotation	0·114	1·30

It seems probable, therefore, that although the available phosphorus and potassium in the soil were both very low as a result of cropping for a hundred years without manure, the phosphorus shortage was more acute than the potassium shortage on the clover section, and was mainly responsible for the lower yield and the large reduction in percentage of ware potatoes.

The PK residues in the soil have increased both the percentages of phosphorus and potassium in the crops and also the yields, and the two effects have accentuated the differences in the uptakes of both nutrients on the unmanured and the fertilizer plots. The results are given in Table 4.

TABLE 4

Phosphorus and Potassium Contents of Potatoes, Agdell Field 1957

	Fertilizer treatment 1848–1951 every 4 years					
	O		PK		NPK	
Rotation	Percentage in dry matter					
	P	K	P	K	P	K
Fallow ...	0·149	1·26	0·206	1·75	0·197	1·87
Clover... ...	0·114	1·30	0·180	1·41	0·186	1·50
	Total nutrients in crops, lb./acre					
Fallow ...	3	24	13	110	13	119
Clover... ...	2	18	7	54	12	96
	Gain from fertilizer residues, lb./acre					
Fallow ...	—	—	10	86	10	95
Clover... ...	—	—	5	36	10	78

The percentages of the two nutrients in the potatoes illustrate the high demand made by this crop for potassium relative to phosphorus. The residues of the PK fertilizers have increased the concentration of phosphorus by one-half and potassium by one-quarter of the values in the crops of the unmanured plots. These increases, together with those in yields of tubers, amount to 5–10 lb. extra P and 36–95 lb. extra K/acre in the crops grown on the residues, and provide evidence additional to that obtained from the Exhaustion Land Experiment on the availability of both phosphorus and potassium accumulated in soils from applications of fertilizers over a long period.

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In the Exhaustion Land Experiment the value of the residues was established only for barley, but even for this crop the experiment supplied no information, by direct measurement, on the adequacy of the PK residues for growing maximum crops, nor on the separate effects of the two nutrients. From the yields of barley and the crop composition it was possible to deduce that the yields were governed mainly by the phosphorus supplies in the soil and that, for these amounts, the potassium residues were more than sufficient. A 2-year scheme of modified cropping and manuring was started in 1957 on part of the Exhaustion Land to give a more complete assessment of the residues. Six crops, barley, wheat, potatoes, sugar beet, swedes and kale are being grown side-by-side, and new dressings of P and K fertilizers have been applied to establish phosphorus and potassium response curves by which to measure the individual nutrient effects of the residues. During the period 1856–1900 wheat was grown for the first 20 years on the site now known as the Exhaustion Land, and potatoes in the remaining years. The average annual dressings of P and K fertilizers were 3 cwt. of superphosphate and 2·5 cwt. of potassium sulphate/acre. The accumulation of fertilizer residues in the soil has therefore occurred under conditions which were abnormal but were favourable to the build-up, for wheat is one of the less-exhausting crops, and the rate of manuring was high. The potatoes, although they have a much higher nutrient requirement, did not yield well.

The results from the Agdell Experiment have a greater interest, since the conditions were nearer normal farming practice. The cropping system followed was a Norfolk four-course rotation, and the manuring was not excessive. PK fertilizers were applied to the roots every fourth year, and were equal to 1 cwt. of superphosphate and 1 cwt. of potassium sulphate/acre for each of the hundred years of the experiment. The uptakes of phosphorus and potassium by the crops of the first eight courses were determined by Lawes and Gilbert. The average yields for the eighteen courses up to 1919 differed little from those for the first eight courses, but by 1930 the crops on the NPK plot were affected by soil acidity. Up to 1919 therefore the estimated average excesses of added fertilizer phosphorus and potassium over the amounts of the two nutrients withdrawn by the crops on the fallow and clover sections of the PK and NPK plots were per year:

Fertilizer treatment	PK		NPK	
	P	K	P	K
	lb./acre			
Rotation with fallow	5	15	8	20
Rotation with clover	3	7	5	10

The higher annual excess of phosphorus on the NPK plot arises from the phosphorus contained in the rape cake applied to this plot, while the higher potassium is due in part to the same cause and in part to the absence of K fertilizer applications on the PK plot for the first 32 years of the experiment. If these excesses have accumulated in the soil in an available form during the past hundred years there would be sufficient phosphorus and potassium for a further ten courses of the rotation.

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The Agdell Soils

Nitrogen

The manuring and cropping treatments have produced marked differences in the nitrogen, phosphorus and potassium contents of the soils. In Table 5 the total nitrogen contents are given of soil samples taken on three occasions, two during the course of the experiment and the third in 1953, 2 years after it had ended.

Table 5

Total nitrogen, as percentage of surface soil (0–9 inches)

	Treatment					
	O		PK		NPK	
Year	Fallow rotation	Clover rotation	Fallow rotation	Clover rotation	Fallow rotation	Clover rotation
1867	0·127	0·130	0·123	0·135	0·129	0·130
1913	0·118	0·141	0·122	0·148	0·127	0·147
1953	0·119	0·152	0·121	0·152	0·118	0·144

On the soils of the fallow rotation the effects of time and manuring are in accordance with those shown by the Broadbalk plots with similar fertilizer treatments (Warren, R. G. 1956: *Proc. Fert. Soc.* 37). The levels of nitrogen on both the unmanured and the PK plots had fallen by 1913 to the same value, 0·12 per cent N (which is a little higher than on Broadbalk) and had not changed during the next 40 years. For the NPK plot there was a small increase over the other two plots, as on Broadbalk, due to the extra nitrogen in the greater plant residues. Unlike the Broadbalk soil, however, the increase in nitrogen of the Agdell NPK plot was not maintained, and by 1953 the level had fallen to that of the unmanured plot. This decrease may possibly be due to the development of soil acidity on the NPK plot, which affected yields after 1930. The explanation must remain in doubt, since weed growth in the cereal crops increased rapidly as the soil became acid and the crop yields fell. No figures are available to show whether the amount of weed growth below the cutter-bar of the binder was less than the amount of plant residues that would be ploughed in after harvesting a good clean crop.

The greatest effect shown by the figures in Table 5 arose from the replacement of fallow by clover, which increased the nitrogen content of the soil by 0·03 per cent. This increase occurred on both manured and unmanured plots, and it is surprising that the soil of the unmanured plot of the clover rotation had increased in nitrogen as much as the soil of the PK and NPK plots in the same rotation. With lower yields on the unmanured plot, and especially of clover, the smaller amounts of crop residues would return less nitrogen to the soil than residues on the manured plots. The records of the Agdell experiment mention frequently the abundance of weeds on the unmanured plot, but, though the weeds would undoubtedly help to conserve soil nitrogen, the source of the additional nitrogen to compensate for the smaller residues of the clover crops is unknown, since the weeds were predominantly non-leguminous.

The extra nitrogen in the soils of the clover rotation towards the end of the experiment as compared with those of the fallow rotation,

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was about 600 lb./acre, but its rate of mineralization to produce inorganic nitrogen for subsequent crops was small. This is illustrated by the yields of the plots which received phosphorus and potassium but no nitrogen fertilizers. Such data provide the only estimate in this experiment of the availability of the accumulated soil nitrogen. The average yields of barley and the mean total nitrogen contents of the soils for the later years of the experiment were:

	PK plots	
	Fallow rotation	Clover rotation
Barley, grain cwt./acre, mean of 10 seasons, 1913–51	10·5	11·6
N per cent in soil, mean of 1913 and 1953 samples ...	0·12	0·15

The results support the conclusion drawn from the Hoosfield Barley Experiment that, at a level of 0·15 per cent N in the soil, the extra amount of old organic matter residues above the amount in a starved soil provides but little nitrogen for barley. However, further tests of the value of the extra organic nitrogen are needed with other crops, especially with those which would benefit from the nitrogen that is mineralized in the autumn.

Phosphorus and potassium

The phosphorus and potassium analyses of the soil samples taken in 1913 and 1953 reflect the manurial treatments, type of rotation, the carting of roots versus the " feeding " of roots on the plots and also the effect on yield of the more acute soil acidity of the NPK plot of the clover rotation.

Although the comparison of carting versus feeding of roots ceased after 1900, the effect (as measured by soil analysis) on the potassium returned to the land on the " fed " portions of the PK and NPK plots was still detectable in the soil samples taken in 1913. The feeding, compared with carting, gave an average increase of 3 mg. readily soluble K/100 g. soil, the amounts being greater on the fallow rotation and less on the clover rotation. This extra potassium had been reduced to negligible quantities by 1953. The two rotation sections of the unmanured plot showed no differences in soluble potassium on either sampling date, nor were there any differences in the effects of the carting and feeding treatments on the nitrogen and phosphorus contents of any of the plots on these occasions.

The changes in phosphorus and potassium contents of the soils due to manuring and crop rotation are set out in Table 6 for the 1913 and 1953 samples, after averaging the results for the carting and feeding sections of the plots.

The moderate dressings of PK fertilizers that were applied in this experiment have increased the readily soluble phosphorus and potassium in the soils, especially of the fallow rotation. By taking a crop of clover or beans once in 4 years instead of a fallow the supplies of these two nutrients were greatly reduced. On all the fertilizer plots, except the PK plot in the clover rotation, the differences over the unmanured plot which were built up in the earlier years continued to increase, and by 1953 the highest values for soluble P and K attained (and especially for potassium) would be

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regarded as adequate for crops other than those having a very high requirement, such as potatoes and sugar beet. On the PK clover rotation plot, unlike the other fertilizer plots, the levels of soluble phosphorus and potassium have remained unchanged during the last 40 years. This difference in behaviour, especially as compared with the NPK clover rotation plot, would appear to indicate some abnormality in the PK plot. It is more probable, however, that the NPK clover plot is the discordant one, owing to the onset of soil acidity during the years 1913–53, which led to lower crop yields and uptakes of nutrients, and consequently to greater phosphorus and potassium residues in the soil.

TABLE 6

Phosphorus and potassium in the Agdell soils 1913 and 1953

Fertilizer Treatment...	O		PK		NPK	
Rotation: fallow (f), clover (c)	f	c	f	c	f	c
	P soluble in 0·5*M*-$NaHCO_3$, mg./100 g.					
1913	0·25	0·20	1·05	0·55	1·00	0·55
1953	0·30	0·20	1·35	0·55	1·15	0·75
	K soluble in 0·5*N*-HAc, mg./100 g.					
1913	8·5	8·5	17·0	13·0	15·5	11·5
1953	9·0	9·0	20·5	14·0	20·0	17·0

The acidity of the clover and fallow parts of the NPK plot, though an unfortunate development for the main objects of the Agdell experiment, has provided some information on the availability of phosphorus in the soil derived from applications of superphosphate given before and during the period of acidity. The clover section was the more acid at the conclusion of the experiment, with about half the area at pH 4·8–5·0 and the remainder at pH 5·2, while the soil of the fallow part was almost entirely within the range pH 5·4–5·6. The chalking carried out in the winter of 1953–54 raised the values to a little above pH 7. In 1956 and 1957, when beans and potatoes were grown to measure the residual values of the PK fertilizers, the yields were good and similar to those on the PK plot, which had not developed acidity. The uptakes of phosphorus given in Table 4 were almost identical for the fallow sections of the two plots, while for the clover sections the amount of phosphorus in the potato crop of the NPK plot which had been acid was greater than that of the PK plot. Although no comment can be made on the state of the phosphorus during the period of soil acidity, the results of the potato crop show that after bringing the soil to pH 7 the availability of the phosphorus residues was at least equal to that of the residues in the soil which had not been acid.

The yields and nutrient contents of the potato crop in 1957 and the soil analyses have established two facts: first, that residues of PK fertilizers have accumulated, and secondly that these residues are available. However, the three types of figures, taken singly or collectively, do not give quantitative estimates of the reserves built up in the soil by the fertilizers. To obtain this information half of each plot will be sown with a crop able to exhaust the soil rapidly, such as grass cut for silage, to which adequate nitrogen

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fertilizer will be given. The value of PK fertilizer residues for a wider variety of crops will continue to be tested in the Exhaustion Land Experiment. As the manuring and cropping treatments of the Agdell experiment have produced a set of soils with different phosphorus and potassium contents, the halves of the plots not put down to grass will be used for a more precise standardization of methods of soil analysis. The Agdell series is much more suitable for this purpose than the series on the Exhaustion Land, where the levels of nutrients are generally either "low" or "medium". With the additional information that would be obtained from this extension of work suggested for Agdell Field, soil analysis could profitably be used more frequently for avoiding the accumulation of fertilizer residues to an unnecessary degree and (of equal importance) to prevent a gradual exhaustion of the soil.

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