SOME RESULTS OF AN EXPERIMENT TO COMPARE LEY AND ARABLE ROTATIONS AT WOBURN

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In the 1930's many midland and eastern counties' farms were run on the so called 'two-compartment' system, with part of their acreage devoted permanently to arable cropping, and the remainder consisting of permanent grass, but this system of farming was already being challenged by the Aberystwyth ley farming school headed by Sir George Stapledon. Many of their ideas which have now become widely adopted were not then generally accepted, and it was to test the proposition that leys benefit the yield of the subsequent arable crops that a long term experiment known as the 'Ley-Arable' experiment was laid down in 1937 at the Woburn Experimental Farm. This paper describes the crop yields obtained in the first 20 years of this experiment, which is still in progress.

The experimental field lies alongside the main Bedford–Leighton Buzzard road (A. 418) midway between the village of Husborne Crawley and Woburn, at an altitude of a little over 300 ft. The site of the experiment covers 2 acres and is almost level. The soil is a sandy loam passing at from 1–2 ft. into a yellow loamy sand derived from the Lower Greensand. Mechanical analysis of soil samples from another part of the same field showed about 60% coarse sand, 20% fine sand, 10% silt and 10% clay. The proportion of silt and clay is rather larger than is usual in soils on the Bedfordshire greensand, perhaps due to downwash from higher ground to the south and also to the presence of occasional thin bands of clay in the greensand. Drainage is good at all times of the year.

The average rainfall for the period 1938–55 was 24·3 in., almost exactly that for the long-period average 1876–1955. A feature of these 18 years has been the frequency of very low and very high rainfalls; in this period there have been 8 years with a rainfall 3 in. or more below the average and 7 years with a rainfall 3 in. or more above the average.

The experimental area had been part of a four-course rotation experiment begun in 1876 to compare the residual value of cake and corn feeding. From 1911 until the start of the present experiment the amounts of cake and corn (fed every fourth year to sheep folded on swedes) had been small and the only other manure had been 3 cwt. superphosphate per acre applied every fourth year. The average yield of wheat and barley in the period 1911–31 was only about 10 cwt. per acre, indicating that by the time the present experiment began the general level of fertility was low.

DESIGN AND CONDUCT OF EXPERIMENT

The experiment compares four rotations as shown in the table below.

The effects of the contrasted cropping in the first 3 years of the rotation have been measured by the yield of the two following crops, potatoes and barley. The experiment consists of five blocks, one for each course of the rotation, (or, in statistical terms, each phase of the 5-year cycle), so that, from the fourth year (1941) onwards, yields of the test crop of potatoes have been obtained every year from one block of the experiment. Each block consists of eight main plots, two for each rotation. Half the plots carry the same rotation throughout the experiment, whilst the other half alternate between the ley and arable rotations. After the first 5 years of

Year ...	1	2	3	4	5
	Treatment crops			Test crops	
(1)	Three years' grazed ley			Potatoes	Barley
(2)	3 years' lucerne cut for hay				
(3)	Potatoes	Wheat*	Seeds hay		
(4)	Potatoes	Wheat*	Kale†		

* Replaced by rye in 1949.
† Replaced by sugar beet in 1945.

the experiment, therefore, there is no replication in any one year. The plots are subdivided for farmyard manure applied at the rate of 15 tons per acre to the test crop of potatoes, the same subplots being dunged for the duration of the experiment.

In the conduct of long-term experiments it has always been a cardinal principle that changes in husbandry must be kept down to a minimum. Unfortunately, a substantial number of changes, some of them unavoidable, have affected both cropping and manuring in this experiment. Of these changes the most serious has resulted from the build-up of potato-root eelworm leading to a partial failure of the treatment crop of potatoes in 1955; from 1956 onwards the test crop of potatoes has had to be abandoned in favour of sugar beet, the treatment crop of sugar beet being replaced by carrots. This paper describes the results obtained up to the change.

Some major changes have also occurred in the treatment crops of the arable rotations. Winter wheat has been a consistently unsatisfactory crop, both in this experiment and in the adjoining six-course rotation experiment. The average yield in the period 1938–48 was only 10 cwt. per acre and in 1949, rye was substituted for wheat and has been very successful. Kale also gave poor results due in part to flea-beetle attack and was replaced in 1945 by sugar beet. Various changes have also been made in the seeds mixtures used for the grazed ley and the hay plots; these are given in the Appendix, Table A.

All plots have received equal quantities of P and K fertilizer, the total amounts over the 5-year period being 1·00 cwt. P_2O_5* and 1·44 cwt. K_2O per acre, of which about half has been applied in the first year of the treatment cropping and the remainder to the first test crop (potatoes). The amounts of nitrogen applied vary according to the crop and are not equal for the different rotations.

Some changes have been made in the manurial treatments in the course of the experiment. Much the most important of these arose from a decision to apply the farmyard manure in the ridges, instead of ploughing it in, from 1948 onwards. In the absence of any test of differential fertilizer dressings in the experiment, consistent figures for the annual response to farmyard manure would have been most valuable. No worthwhile estimate of trends in the effect of farmyard manure can now be obtained, the change having occurred in the middle of the second cycle.

Most of the other changes, listed in Appendix B, have been increases in the basal dressings of nitrogen. In 1949 the changeover from wheat to rye was made the occasion for an increase in nitrogen from 0·2 to 0·5 cwt. N per acre and a similar change was made for the hay plots. The use of N on the grazed ley was also substantially increased at about the same time.

In 1955, consideration of the relatively low level of basal manuring, together with symptoms of nitrogen and potash shortage, led to each plot of the test crop of potatoes being split into four for the application of additional dressings of N and K, factorially, at double the basal rates. The changes in cropping on account of potato-root eelworm have provided an opportunity to increase the amounts of fertilizer applied and to adopt differential manuring according to crop requirement.

In addition to these deliberate alterations made in the original experimental scheme, there have also been changes in management and husbandry whose effects, although difficult to isolate, may well have been substantial. A further factor has been the virtual elimination of rabbits by myxomatosis in recent years. Previously rabbits had been very prevalent in the area, and as the field was not wired a good deal of damage occurred.

RESULTS

Yields are now available for 15 years (i.e. three complete cycles) for the two test crops, potatoes (1941–55) and barley (1942–56); treatment means for each 5-year period are given in Tables 1 and 3, the figures shown being the mean of the continuous and alternating series. Except in one or two seasons the experimental errors for the test crop of potatoes have been low throughout the experiment, the split plot errors shown in Table 1 being about 3% of the mean yield.

Where no farmyard manure has been applied there has been a general decline in yield of potatoes in the third 5-year period, this decline being small for the plots following the grazed ley, but substantial for the arable rotations. From the outset of the experiment there have been well-defined differences in yield of potatoes according to the 'treatment' cropping, the lowest yields being those following the continuous arable rotation, with progressively higher yields from the arable with hay, lucerne, and grazed ley rotations. These differences remained much the same in the second 5-year period, whereas in the last 5 years the superiority of the grazed ley plots has become more marked.

A rather similar gradation of yields from the purely arable cropping through arable with hay to the lucerne and ley rotations is found for the plots receiving farmyard manure also, but the differences are less marked than in the absence of farmyard manure. The high yields of potatoes following lucerne are noteworthy, but there is some indication that the grazed ley plots may have been gaining ground in the last 5 years.

* Increased to 1·16 cwt. P_2O_5 in 1950.

Generally speaking, differences between the 'continuous' plots, which follow the same rotation throughout the experiment, and the 'alternating' plots which carry the arable and ley rotations alternately, have been fairly small. Yields of the test crops have been determined mainly by the cropping in the cycle immediately preceding the test cropping and only to a small extent by the cropping in earlier cycles. Table 2 shows that for potatoes after ley or lucerne there was no consistent difference between plots that had been continuously under the ley rotations and those which had alternated with arable; the further subdivision of the alternating plots for the comparison of hay against kale or sugar beet (not shown in the table) also shows no evidence of an effect on yield. Similarly, the arable rotation which includes a 1-year ley for hay shows no evidence of benefit from an earlier cycle in leys, whether the grazed ley or the hayed lucerne. Only the purely arable rotation shows benefit from a previous cycle under leys, the average gain in the 10-year period being 1·2 tons per acre, almost all of this being due to lower yields in the last 5 years.

The barley yields show a large upward trend over the period under review. Pest attack was often severe in the early years and consequently up to about 1946 plot errors were often very high, exceeding 20 % for both whole- and split-plots in some seasons; with increasing yields the errors have fallen sharply, the split-plot error for each of the last 5 years lying between 3 and 7 % of their mean yields. At the same time treatment effects have become more evident. For barley these effects have been rather different from those just described for potatoes, in that whether or not farmyard manure has been applied, the grazed ley and lucerne rotations have given similar yields. The level of yield after the arable rotations has shown a much less pronounced upward trend, and for the 5 years 1951–6 mean yields were below those of the grazed ley and lucerne plots, by about 20 % where no farmyard

Table 1. *Mean yields of potatoes: total tubers in tons per acre*

Previous treatment	No farmyard manure: Ley (grazed)	Lucerne (hay)	Arable (hay)	Arable (kale or sugar beet)	Farmyard manure: Ley (grazed)	Lucerne (hay)	Arable (hay)	Arable (kale or sugar beet)	S.E. (1)	S.E. (2)
1941–5	12·62	12·06	11·10	9·98	13·14	14·09	12·47	12·13	±0·40	±0·86
1946–50	12·34	11·83	10·36	10·46	14·28	14·59	13·67	12·50	±0·27	±0·76
1951–5	11·88	9·79	8·68	7·42	14·32	13·72	12·45	11·46	±0·36	±0·71
1941–55	12·30	11·23	10·05	9·29	13·91	14·13	12·86	12·03		

Standard errors: (1) Split-plot error applicable to the effect of farmyard manure within any one crop sequence. (2) For all other comparisons.

Table 2. *Effects of alternating ley and arable cropping on yield of potatoes* 1946–55 (*tons total tubers per acre*)

	No farmyard manure: Ley (grazed)	Lucerne (hay)	Arable (hay)	Arable (kale or sugar beet)	Farmyard manure: Ley (grazed)	Lucerne (hay)	Arable (hay)	Arable (kale or sugar beet)
Continuous	12·41	10·80	9·19	8·47	14·00	14·46	13·18	11·24
Alternating	11·86	10·82	9·85	9·41	14·59	13·86	12·94	12·71

Table 3. *Mean yields of barley: total grain in cwt. per acre*

Previous treatment	No farmyard manure: Ley (grazed)	Lucerne (hay)	Arable (hay)	Arable (kale or sugar beet)	Farmyard manure: Ley (grazed)	Lucerne (hay)	Arable (hay)	Arable (kale or sugar beet)	S.E. (1)	S.E. (2)
1942–6	16·0	19·1	14·3	16·8	15·4	18·2	17·6	16·4	±1·45	±2·73
1947–51	20·5	20·6	18·1	18·9	21·6	21·5	19·5	21·6	±0·82	±2·89
1952–6	30·9	29·3	25·8	23·8	33·1	33·4	30·2	28·4	±0·92	±1·80
1942–56	22·5	23·0	19·4	19·8	23·4	24·4	22·4	22·1		

Standard errors: (1) Split-plot error applicable to the effect of farmyard manure within any one crop sequence. (2) For all other comparisons.

manure had been applied and by about 10% with farmyard manure.

The treatment crops themselves give some information on the effects of preceding rotations and on the residual effect of farmyard manure. Mean yields of lucerne hay are shown in Table 4.

The yields of lucerne hay have increased substantially since 1938. The increase in yield in the seeding year can be largely accounted for by a change in sowing date: up to and including 1948 the average date of sowing was 10 May (range 1 May–20 May), whereas from 1949 the mean date has been 12 April (range 26 March–30 April), the mean yields being respectively 0·5 and 1·3 tons per acre. The change from Provence to Du Puits in 1950 (see Appendix A) may have been a contributory factor. Yields of hay from the second year of lucerne have increased irregularly from 2–2½ tons per acre at the outset of the experiment to almost 4 tons per acre in the last 6 years. In the middle period the yield of hay from the third year of lucerne was substantially greater than from the second year of the crop, but in the last 5 years the yield in the second year has caught up and sometimes exceeded that in the third year. Differences between the alternating and continuous plots and between those with and without farmyard manure were generally small up to the 1949 sowing. Since then there has been clear evidence of the residual effects of farmyard manure, and without farmyard manure the plots on which lucerne alternates with arable crops have given better yields than those where lucerne is grown continuously. Lucerne in this experiment has never been inoculated, and it has been suggested that the slow changes could be the result of a build-up in numbers of nitrogen-fixing bacteria; this is unlikely to be so, because lucerne has never shown any benefit from inoculation on other parts of the same field, and the alternating plots, which have carried lucerne only once, show just as marked an upward trend as the continuous plots.

The yield of the grazed ley has been recorded in terms of sheep grazing days per acre, and at the same time clippings have been made immediately before the start of each grazing period. In some of the war years, it proved impossible fully to graze the plots and the yields of the grazed ley given in Table 5 refer to 1944 onwards. From 1946 onwards a net figure is available for the yield of grass, the residue left after grazing having been deducted; the average percentage deduction (10%) for the period 1946–55 has been applied to the figures for 1944 and 1945. The slow changes over the period 1938–56 cannot be assessed with much precision, but there is no indication of increasing yields in the later years, as there is for lucerne. The yields given in Table 5 show only small differences between the continuous and alternating series of plots; farmyard manure has given

Table 4. *Changes in mean yields of lucerne hay* 1938–56 *and effects of farmyard manure and previous cropping* (*tons hay* (85% D.M.) *per acre*)

	First year			Second year			Third year		
	1938–42	1943–8	1949–56*	1939–43	1944–9	1950–6*	1940–4	1945–50	1951–6*
Continuous									
No farmyard manure	—	0·51	1·13	—	2·56	3·35	—	3·46	3·10
With farmyard manure	—	0·53	1·63	—	2·74	4·28	—	3·61	3·78
Alternating									
No farmyard manure	—	0·39	1·24	—	2·56	3·84	—	3·82	3·77
With farmyard manure	—	0·46	1·34	—	2·71	4·15	—	4·08	4·01
Mean	0·55	0·47	1·34	2·16	2·65	3·90	2·84	3·74	3·66

* Excluding the 1950 sowing, two plots of which suffered storm damage.

Table 5. *Effect of farmyard manure and previous cropping on yields of grazed ley* 1944–56

	Hay equivalent of grass (tons per acre)				Sheep days per acre			
	Year			Total	Year			Total
	1st	2nd	3rd	(3 years)	1st	2nd	3rd	(3 years)
Continuous								
No farmyard manure	2·8	4·8	5·3	12·9	995	1874	1802	4671
With farmyard manure	3·1	5·1	5·8	14·0	1091	1852	1832	4775
Alternating								
No farmyard manure	2·7	4·7	5·0	12·4	940	1837	1706	4483
With farmyard manure	2·8	5·5	5·6	13·9	999	1920	1843	4762
Mean	2·8	5·0	5·4	13·2	1006	1871	1796	4673

some increase in yield, its apparent effect being small in terms of sheep days but over 10% when estimated from grass clipping.

Turning to the treatment crops of the arable rotations, for potatoes there have been 2 years of particularly low yields in the latter part of the period, one of which is certainly, and the other possibly, due in part to attack by potato-root eelworm, but otherwise there has been no general trend in yield.

Table 6 shows that for potatoes without farmyard manure yields on the continuous arable plots are fairly similar to those shown (for a slightly different set of years) in Table 1; but the reduction in yield due to taking a root crop instead of seeds hay is here very slight. The beneficial effect of the leys is less after the grazed ley than after arable. The effect of the lucerne ley has varied from crop to crop but has always been less than that of the grazed ley. The residual effect of farmyard manure, applied 4 years earlier to the test crop of potatoes, is substantial, increases varying from 10–20%, except after the grazed ley where they are only of the order of 5%. A rise in sugar yield during the period is no doubt due in part to the substitution of nitrate of soda for sulphate of ammonia in the later years. The yield of hay from the 1-year ley has increased from an average of about 1½ tons per acre in the first 5 years to about 3 tons per acre in the last 5 years, no doubt due to changes in seeds mixture (Appendix A), increased dressings of nitrogen (Appendix B) and, probably, unrecorded variations in management.

Table 6. *Effect of farmyard manure and previous rotation on yield of arable treatment crops*

	Potatoes 1943–56*	Wheat 1944–8	Rye 1949–56	Hay† 1945–56	Sugar beet† 1946–55
		Continuous arable			
After hay					
No farmyard manure	9·41	9·0	30·3	52·8	—
Farmyard manure‡	11·27	10·6	32·3	58·4	—
After kale or sugar beet					
No farmyard manure	9·41	9·8	29·6	—	33·9
Farmyard manure‡	10·86	11·8	31·4	—	41·2
				±1·2	±1·93
		Alternating			
After lucerne					
No farmyard manure	9·85	12·1	33·0	53·4	37·8
Farmyard manure‡	12·11	12·3	33·3	65·2	41·1
				±2·2	±1·74
After grazed ley					
No farmyard manure	11·22	13·9	32·7	64·0	38·3
Farmyard manure‡	12·57	13·9	33·3	67·2	40·2
	±0·21	±1·13	±0·61	±1·0	±1·14

* Excluding 1955.

† The yields after lucerne and after grazed ley have been adjusted for seasonal differences: potatoes, tons total tubers per acre; wheat, rye, cwt. total grain per acre; hay, cwt. hay (85% dry matter) per acre; sugar beet, cwt. total sugar per acre.

‡ Applied to *test* crops of potatoes.

marked at this point in the rotation than for the test crop of potatoes, but is still considerable (1·8 tons per acre or 19%) for the grazed ley compared with continuous arable. Farmyard manure has continued to give substantial increases in yield, the average increase being 1·7 tons per acre (17%) or about two-thirds of the effect of the direct application 2 years earlier.

In the absence of farmyard manure, the cereal crops have also shown increases in yield due to previous rotation, but the mean increase of about 3 cwt. grain for rye is proportionately much less than for the root crops and for the third cycle of barley. It should be noted that the basal dressing of N was 0·62 cwt. per acre for rye compared with 0·21 cwt. for wheat and barley. There is again some response to residual farmyard manure on the continuous arable plots, but not after the leys.

Without farmyard manure, yields of both hay and sugar beet were also higher by some 15–20%

In general, there has been a very considerable increase in the total amount of produce removed from the plots carrying the arable rotations in the latter half of the experimental period. Thus, since 1948 the average level of the cereals has been about 30 cwt. grain compared with little more than 10 cwt. before, with corresponding differences in the amounts of straw carted off. Similarly, a very moderate crop of kale, with an average yield of about 5 tons green material has been replaced by a much more productive beet crop, whose combined yield of roots and tops (all carted off) is usually of the order of 20 tons.

Taking the above results as a whole, there has clearly been a much increased off-take of green material, and therefore of plant nutrients, from all rotations except the grazed ley. At the same time there has been no increase in the amount of fertilizers other than nitrogen, supplied to the crops above the low levels fixed at the beginning of the experiment.

DISCUSSION

At first sight the results of this experiment appear to provide a clear-cut verdict in favour of ley farming and, indeed, they have often been quoted in this sense. The applicability of these results to practice is, however, severely limited by the conditions under which the experiment has been carried out. Taking first the potato crop, it has already been mentioned that there has been a serious build-up of potato-root eelworm in the experiment; the infestation had, however, passed unnoticed until revealed by total failure of large areas of the treatment crop of potatoes in the dry weather of 1955. For the arable rotations the period during which the land was free of potatoes was dangerously short, the block (block IV) on which failure occurred having grown eight crops of potatoes in 18 years. Considering that after mild winters numbers of ground keepers have sometimes been present in the following corn crop it is perhaps surprising that serious eelworm attack had not become obvious before. A report to the Rothamsted Field Plots Committee by Dr D. W. Fenwick in January 1956 showed that only one of the five blocks (block II) had consistently low cyst counts and plots considered to be definitely unsafe for potatoes occurred on all other blocks. As potatoes have been grown twice as often on plots carrying continuous arable rotations as on those carrying the continuous ley and lucerne, the former are much the most heavily infested, all except those on block II being classed as definitely unsafe for potatoes. Although the continuous ley and lucerne plots have little or no eelworm population, the alternating plots are by no means free of infestation. Except for block II, therefore, which last carried potatoes in 1954, it must be assumed that all the treatment comparisons involving potatoes in the third cycle (i.e. from 1952 onwards) have been to a greater or lesser extent affected by eelworm. The accentuation of the difference in potato yield after arable crops and after leys, observed in the third cycle, must be due in part at least to this cause.

A second factor which may have substantially influenced the results is the low level of basal manuring. The Rothamsted Report for 1938 states clearly that it was the intention of the designers to test the effects of farmyard manure and of the different rotations in the presence of a liberal basal dressing of inorganic fertilizers. By the standards of that time they did in fact do so, although the amounts of P and K applied to the whole five-course rotation are no more than is commonly applied to a single crop of potatoes to-day. At the same time it was decided to manure all rotations equally with P and K, regardless of the large difference between the nutrient requirements of the grazed ley rotation on the one hand, and the continuous arable and lucerne rotations on the other. This was undoubtedly a mistake, although its effects might not have been important had the amounts applied been sufficient to ensure that yields even on the rotation with the higher potash requirement, would not be limited by lack of fertilizer. As it happened, the partial failure of the wheat and kale crops, coupled with the low level of nitrogen, to some extent restricted the off-take of nutrients in the early years of the experiment, and it is only in the later years that there have been signs that the soil potash reserves might be depleted.

No reliable balance sheet of nutrients applied and withdrawn in the crops can be produced, for at no time during the period covered by this report have crop samples been chemically analysed. Bearing in mind the substantial differences in nutrient uptake from field to field and year to year, an estimate of the probable nutrient balance derived from analyses of crops grown in different conditions from those of the experiment are liable to be considerably in error. Table 7 gives such a balance sheet for P and K, based mainly on the average values given in 'Rations for Livestock' (Woodman, 1957). It seems improbable that there can have been any depletion of the considerable phosphate reserves, and there may have been a small build-up on the plots receiving farmyard manure. For potash, on the other hand, the plots carrying the more exhausting rotations must have suffered losses even where farmyard manure is applied. In the absence of farmyard manure the losses may have been of the order of 0·4–0·5 cwt. K_2O per acre yearly in the first cycle of the lucerne and arable (kale) rotations, increasing to 0·6–0·7 cwt. per acre yearly in the third cycle.

Table 7. *Estimated amounts of phosphate and potash withdrawn in crops and applied as manures (cwt.* P_2O_5 *and* K_2O *per acre: total over five crops)*

	Ley (grazed)	Lucerne (hay)	Arable (hay)	Arable (kale or sugar beet)
Phosphate (no farmyard manure)				
In crops	0·7	1·3	1·0	1·3
Applied	1·0	1·0	1·0	1·0
Balance	0·3	−0·3	0·0	−0·3
Phosphate (with farmyard manure)				
In crops	0·8	1·5	1·2	1·5
Applied	3·0	3·0	3·0	3·0
Balance	2·2	1·5	1·8	1·5
Potash (no farmyard manure)				
In crops	2·2	4·5	3·1	4·0
Applied	1·5	1·5	1·5	1·5
Balance	−0·7	−3·0	−1·6	−2·5
Potash (with farmyard manure)				
In crops	2·4	5·2	3·7	4·6
Applied	4·3	4·3	4·3	4·3
Balance	1·9	−0·9	0·6	−0·3

In other experiments at Woburn potash responses have generally been small, but it would be surprising if such a long-continued drain on the soil reserves could fail to affect yield. In the absence of farmyard manure, lucerne and clovers have shown the characteristic symptoms of potash shortage in recent years. For potatoes and sugar beet, however, potash-deficiency symptoms have usually been slight, the principal visual symptom on the plots carrying the arable rotations being the pallor usually associated with nitrogen deficiency. The soils are now being chemically analysed, and it will be most interesting to see how far the nutrient status of the soil has been affected by the differential cropping.

That the nitrogen requirements of the arable rotations might be greater than that of the ley rotations was recognized at the outset of the experiment, and so the amounts of nitrogen were not uniform over all rotations, the total dressings over the 3 years of treatment cropping varying from 1·0–1·5 cwt. N per acre for the two arable rotations to 0·2 cwt. N and nil for the 3 years of grazed ley and lucerne, respectively. It is clear that the nitrogen requirements of the Woburn soil were seriously underestimated; had the existing results of the adjoining six-course rotation experiment been taken into account, much larger dressings of nitrogen would have been applied to both roots and cereals. Ideally, the plots might have been split for N as well as for farmyard manure.

In fact no test of differential quantities of nutrients was made until 1955, when to see how far nitrogen and potash supply was restricting yield, the plots carrying the test crop of potatoes were split into four subplots. The original levels of N and K were compared with double those quantities, the treatments being tested factorially. The yield was only moderate due to an unusually dry summer; the fertilizer subplots gave results of low accuracy (percentage standard error about 15%) perhaps due in part to the varying incidence of eelworm. The mean yields of potatoes and mean responses to N and K are given in Table 8.

Crops in general did not respond well to N and K in this dry season and on the adjoining six-course experiment the response of 0·67 tons per acre to 0·6 cwt. N per acre was one of the smallest increases in the 15 years under review. Nevertheless, Table 7 shows that there were sizeable increases in yield from extra quantities of both nutrients except after the grazed ley. Whilst these figures provide some confirmation for the idea that shortage of N and K has reduced the yields of the arable rotations, the superiority of the ley plots is such that it might well be questioned whether any quantity of fertilizers applied to the arable plots would have sufficed to increase their yields up to the level of those after ley.

At Woburn the prime factor limiting yield is water supply, and after water, nitrogen is next in importance. The results of another experiment at Woburn have shown that potato yields may be doubled by irrigation in dry seasons. In such years nitrogen responses tend to be small at Woburn, although often very large indeed in wet seasons; however, under irrigation large nitrogen responses have been obtained in dry seasons also. From this it would be natural to expect that the superiority of the plots after ley might be due to the ability of the soil on these plots to retain moisture in dry periods, or alternatively, for the nutrients it contains to be more readily available to the growing plant in dry periods. In the dry spring and summer of the present year (1957), for example, the halves of the arable plots which received farmyard manure have made markedly better growth than the halves without farmyard manure, whilst the effect of extra fertilizers has been slight up to the time of writing (July). However, examination of the potato yields in relation to summer rainfall gives no support for this theory.

Table 8. *Yield of potatoes (total tubers)*—1955

	Ley (grazed)	Lucerne (hay)	Arable (hay)	Arable (sugar beet)	S.E.
Mean yield	8·86	8·46	7·20	6·09	—
Response to extra N	−0·21	1·19	1·20	0·39	±0·59
Response to extra K	−0·23	1·76	0·22	0·71	±0·59

N, 0·56 *v.* 1·12 cwt. N per acre.
K, 0·84 *v.* 1·68 cwt. K_2O per acre.

If we restrict our attention to the 10 years 1941–50, in order to exclude the possibility of differences between the ley and arable series being due to eelworm attack, we find that the years happen to divide themselves into 5 years with rather wet summers (1941, 1944, 1946, 1948 and 1950) and 5 relatively dry years. The mean yield of test-crop potatoes over all treatments and the differences grazed ley–arable (kale or sugar beet) for these two groups of years are given in Table 9.

Average yields over all treatments have tended to be higher in the wetter seasons. Potatoes following the grazed ley have usually given higher yields than those following arable cropping, but the benefit from the ley has been distinctly less in dry than in wet seasons. Lucerne has given much the same figures as the grazed ley, the arable with hay being intermediate between the leys and the arable (kale or beet).

The most likely explanation of this result is that in all years, but especially in wet years, when nitrogen responses are greatest, the arable plots are seriously short of nitrogen. Certainly the visual appearance of the crops has suggested very strongly that the chief difference between the treatments has been in the availability of nitrogen. In this connexion it may be significant that rye, which is the only crop receiving anything like an adequate amount of N for Woburn conditions, shows much the smallest residual effects of treatments of all the crops tested.

Apart from the one year (1955) in which plots carrying the test crop of potatoes were split for additional N and K, the present experiment has provided no information on how crop yields following the different rotation treatments would have been affected by higher or lower levels of the basic fertilizer. So far as the arable rotations are concerned, however, some indications of the possible effect of greater nitrogen dressings can be obtained from the immediately adjoining six-course rotation experiment. The results for the period 1930–55 have been summarized by Yates & Patterson (1958). Unfortunately, here also the amounts of nitrogen tested have for most crops been far below the optimum, the highest of four levels tested being only 0·6 cwt. N per acre. However, the results suffice to show that, up to this level, responses of potatoes, sugar beet, wheat and rye have been nearly linear, indicating that much greater amounts could have been applied before the point of maximum yield was reached. Even for barley, which in the ley-arable experiment has received only 0·21–0·25 cwt. N per acre, the most profitable dressing in the six-course experiment is above 0·6 cwt. N per acre, the highest rate tested. It is possible, therefore, that the observed differences in yield between the experimental treatments may be explained simply with reference to the nutrients provided by the residues of the leys, rather than by invoking any special effects of organic matter on soil structure or water retention. (It is also possible that on the arable plots which do not receive farmyard manure there is a deficiency of some other element, such as magnesium.) Under the revised scheme of cropping and manuring instituted in 1956 the testing of extra quantities of N and K on split plots for the first test crop has been retained so that in due course further information should be obtained. It will, however, refer to sugar beet, a crop with a habit of growth very different from that of potatoes.

At the time of writing, no investigation has been made of the effect of the experimental treatments on soil structure or on the organic matter content of the soil. Casual observation does not suggest that there has been any dramatic build-up of organic matter after the ley treatments, and indeed such a build-up would scarcely be expected under Woburn conditions. This is borne out by figures given by Barnes (1950) for percentage total N in oven-dry soil, of samples taken from the experimental plots in the winter preceding the test crop of potatoes in the period 1941–8. These results and those from a further sampling in 1956 (Block III) and 1957 (Block V, plots without farmyard manure only) were as follows:

	Mean % nitrogen	
	1941–8	1956–7
After grazed ley	0·1165	0·108
After hayed lucerne	0·1146	0·104
After arable with kale or sugar beet	0·1126	0·096
After arable with hay	0·1115	0·102
Standard error	0·0026	—

The errors are considerable but there is an indication that the total N percentages in plots carrying the arable rotations may have decreased somewhat relative to those of the other rotations. From these results it must be concluded that no spectacular build-up has taken place as a result of the cropping with leys; indeed the variations from block to block at the outset of the experiment were greater than those achieved by almost 20 years of differential cropping.

Table 9. *Effect of season on mean yield and on benefit from leys* 1941–50 (*Potatoes, tons total tubers per acre*)

	Rainfall April–Sept. (in.)			Benefit from ley*		
	Mean	Range	Mean yield	Without farmyard manure	With farmyard manure	Mean
5 wet years	15·1	12·2–18·2	12·43	2·93	2·22	2·57
5 dry years	8·4	6·4–10·2	10·28	1·64	0·57	1·10

* Difference: grazed ley minus arable (kale or beet); mean of continuous and alternating series.

SUMMARY

The effect of short leys and arable cropping on the yields of the following arable crops has been tested since 1937 at Woburn Experimental Farm, Bedfordshire. The leys were a 3-year grazed ley and 3 years of lucerne cut for hay and the arable cropping

was potatoes, winter cereal and either a 1-year ley or a third tillage crop. The effects of these crop sequences were measured by test crops of potatoes and barley, uniformly treated except that 15 tons farmyard manure was applied on one-half of each plot for potatoes.

Without farmyard manure, the yield of potatoes after the grazed ley was higher than after three tillage crops by an average of about 3 tons per acre; after lucerne it was about 2 tons per acre more than after the tillage crops and after the 1-year ley under 1 ton per acre more. With farmyard manure the benefit from leys was less (about 2 tons per acre for both lucerne and the grazed ley). The average effect of the farmyard manure was about 2·8 tons except after the grazed ley, where the increase was only 1·6 tons per acre.

Effects of the previous cropping on the yield of barley were small in the early years of the experiment, but in the last 5 years the yield after ley and lucerne has exceeded that after the tillage crops by about 15%.

Part of the difference in potato yield between the ley and arable sequences can be attributed to the differential incidence of potato-root eelworm, which has reached a high level of infestation on some of the arable plots. Much of the remainder may be ascribed to the low level of basal manuring which has affected the yield of all plots, but particularly those under tillage crops. How far the observed differences can be explained by these considerations remains a matter for speculation, but may to some extent be clarified when further results are obtained from a revised scheme of cropping and manuring.

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APPENDIX A. SEEDS MIXTURES AND VARIETIES

Seeds mixtures

	1938–40	1941–7	1948–54	1955–6
Grazed ley				
Italian ryegrass	—	10	—	—
Perennial ryegrass S. 23	14	14	21*	20*
Cocksfoot S. 143	8	8	12	11
Late-flowering red clover S. 123	4	4	6	6
White clover S. 100	—	2	3	3
Wild white clover	2	—	—	—

* 1951–6: S. 24, not S. 23.

	1940–4	1945	1946–7	1949–55	1956
1-year ley for hay					
Italian ryegrass	16	24	24	—	—
Perennial ryegrass	—	—	—	27	19
Broad red clover	10	12	—	—	—
Montgomery red clover	—	—	12	12	9
Alsike	—	—	—	3	2

The seeds sown in wheat in 1947 failed and in spring 1948 the following mixture was sown: Giant Italian ryegrass (22 lb.), Trifolium (27 lb.)

Varieties

Lucerne	1939–44 and 1947–9, Provence; 1945, Grimm; 1946, Argentine; 1950–6, Du Puits
Potatoes	1938–56, Majestic
Barley	1938–55, Plumage Archer; 1956, Herta
Wheat	1939–47, Red Standard; 1948, Atle (spring sown)
Rye	1949–56, King II
Kale	1938–44, Thousand Head
Sugar beet	1945–56, Klein E

APPENDIX B. CHANGES IN MANURING

Course of rotation	Crop	Year	cwt. N	cwt. P_2O_5	cwt. K_2O*
1–3	Grazed ley				
	1st year	1938–49	0·21(1)	0·50	0·72
		1950–4	0·22(2)	0·60	0·60
		1955	0·33(2)	0·60	0·60
	2nd and 3rd years	1938–48	0·00	0·00	0·00
		1949–54	0·16(2)	0·00	0·00
		1955	0·33(2)†	0·00	0·00
1–3	Lucerne 1st year	1938–49	0·00	0·50	0·72
		1950–5	0·00	0·60	0·60
1	Potatoes (treatment crop)	1938–49	0·63(1)	0·50	0·72
		1950–5	0·63(1)	0·60	0·60
2	Wheat or rye	1938–48	0·21(1)	0·00	0·00
		1949–55	0·50(2)	0·00	0·00
3	Kale or sugar beet	1938–46	0·63(1)	0·00	0·00
		1947–55	0·63(3)	0·00	0·00
3	Hay	1938–48	0·21(1)	0·00	0·00
		1949–53	0·50(2)‡	0·00	0·00
		1954–5	0·50 *v.* 0·66(2)‡	0·00	0·00
4	Potatoes§ (test crop)	1938–49	0·63(1)	0·50	0·72
		1950–4	0·56(1)	0·56	0·84
		1955	0·56 *v.* 1·12(1)‖	0·56	0·84 *v.* 1·68‖
5	Barley	1938–48	0·21(1)	0·00	0·00
		1949–55	0·25(2)	0·00	0·00

(1) Sulphate of ammonia. (2) 'Nitro-Chalk'. (3) Nitrate of soda.

* Potash applied as sulphate 1938–43; as muriate from 1944 onwards.

† In two doses one after 1st and one after 3rd grazing.

‡ In two doses one in spring (0·33) and the remainder after the first cut; in 1954 and 1955 the plots were subdivided to test 0·16 *v.* 0·33 cwt. N for the second dressing; the spring dressing was unaffected.

§ Farmyard manure at the rate of 15 tons per acre applied on half-plots; up to 1947 the dressing was ploughed in during the winter, from 1948 onwards it was spread in the ridges before planting.

‖ In 1955 the plots were subdivided into four to test factorially the effect of doubling the level of N and K. The subplots which did not receive the extra K for potatoes received a further 0·84 cwt. K_2O per acre after the potatoes were lifted.