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The Effects of Ley and Arable Cropping Systems on the Amounts of Soil Organic Matter in the Rothamsted and Woburn Ley–Arable Experiments

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Introduction

The Agricultural Advisory Council's (1970) report commented on the importance of soil organic matter and gave prominence to critical values for the amounts needed in certain soils. In the report it was suggested that short leys could increase the amount of soil organic matter but no indication was given of the size of the increase that might be expected. Experiments comparing ley and arable systems of cropping have been made at Woburn and Rothamsted for more than 30 and 20 years respectively and changes in the amounts of soil organic matter under the contrasted systems have been measured. d'Arifat and Warren (1965) summarised some of the results of the Rothamsted experiments at the end of the first 12 years. This account extends those results and continues them for a further nine years during which time there were some major changes in the management of the experiments. The results of the Woburn experiment have not been discussed previously.

Part 1. The Rothamsted Ley–Arable experiments, 1949–72

The experiments

These two experiments, although situated about a mile apart on Rothamsted Farm, are both on soil of the Batcombe Series, undifferentiated phase, which is a flinty silt loam or loam over Clay-with-flints. Before the experiments started in 1949 the histories of the two sites were very different. The experiment on Highfield followed very old permanent grass whilst that on Fosters Field followed long-continued arable cropping. Since the start of the experiments both had the same management with cultivations, drilling and harvesting done on the same or succeeding days.

The main part of each experiment was the comparison of four contrasted cropping systems, each lasting three years, and the measurement of their effects on yields of three arable test crops (winter wheat, potatoes, barley) that followed. Initially one of the systems tested was a grazed ley but sheep grazing had to be abandoned, not least because the sheep were worried by dogs when penned on the plots. Starting in 1962 the grazed ley was replaced by a grass–clover ley receiving no nitrogen fertiliser; this was compared with an all-grass ley receiving 75 kg N/ha for each cut taken at silage stage. This ley-with-N replaced a grass–clover ley, given much smaller amounts of N, the grass was cut and removed at hay or silage stage. The treatment cropping systems tested were:

1. Three-year arable rotation (A): one-year seeds hay, sugar beet, oats.
2. Three-year lucerne (Lu): lucerne cut for hay.
3. Three-year grazed ley (L): a grass–clover ley given only a little N was grazed by sheep; subsequently a three-year grass–clover ley without N (Lc) was cut and removed at silage stage.
4. Three-year conserved ley (Cg): a grass–clover ley given only a little N was cut and removed at hay or silage stage; subsequently a three-year all-grass ley (Ln) was given 75 kg N/ha for each cut taken at silage stage.

In addition, at the start of the experiments some plots were (a) sown to grass intended to remain down longer than the three-year leys, 'reseeded grass', and (b) on Highfield only, some plots were left with the original sward unploughed, 'permanent grass'. Both reseeded and permanent grass were given little N and were grazed by sheep except when a hay crop was taken once in three years, 1949–54, subsequently once in six years (when the seeds hay crop was taken in the all-arable rotation in each block). When grazing ceased, plots with both treatments were halved and the half plots managed either as the all-grass ley with N or as the grass–clover ley without N. This change in management was made on the permanent grass in 1962 and on the reseeded grass it was phased in, starting in 1963, on those blocks where it was not intended to plough. These treatments were:

1. Reseeded grass (R): reseeded at the start of the experiment, grass–clover with little N, grazed by sheep, subsequently a split-plot test of grass with much N (Rn) and grass–clover without N (Rc).
2. Permanent grass (G): Highfield only, the original sward unploughed and given little N, grazed by sheep, subsequently a split-plot test of grass with much N (Gn) and grass–clover without N (Gc).

In both the reseeded and permanent grass there was some clover at the start of the experiments, this was not eliminated by the small nitrogen dressings given. In both the Rc and Gc swards the amount of clover increased when N dressings ceased whilst with the increased fertiliser N dressings to the Rn and Gn swards the clover was eliminated.

Three years of treatment cropping followed by three years of test crops gave a six-year cycle and, as each phase was in duplicate, each experiment consisted of 12 blocks. Each block had five plots, one each for the arable, lucerne, cut grass and grazed ley systems and one for the reseeded grass, whilst on Highfield there was a sixth plot of permanent grass. In 1949 the experiments started with two blocks for first year treatment crops and two blocks with the first of the test crops. The remaining blocks were phased in with treatment and test crops over the following two years so that half the blocks started with treatment crops and half with test crops. The grass sward on Highfield was not ploughed until the autumn before each block was phased in. On Fosters, arable cropping was continued until the blocks were required. Boyd (1968) summarised yield results to 1967. For details of seed mixtures, manuring and management see Rothamsted Experimental Station (1970).

Results

At the start of the experiment ploughing was shallow, not more than 15 cm deep especially on Highfield, but the depth of the plough layer was gradually increased to about 23 cm as more powerful tractors were used for ploughing. It is not known what effect this gradual deepening of, and incorporation of subsoil into, the plough layer might have had on the accumulation and breakdown of soil organic matter but the results suggest that any effects were very small. Details of the methods of sampling and analysis are given in the Appendix; all results are given as % carbon (Tinsley method) in air-dry soil 0 to 22·5 cm depth of soil. All blocks were not sampled at the start of the experiments but results from those that were suggested that in 1949 Fosters, the old arable field, had about 1·65% C, whilst Highfield, long in permanent grass, had about 2·75% C. These results are most probably correct for on Fosters the carbon content has remained about 1·55% C (mean of all cropping systems other than R). On Highfield samples taken in 1972 from two areas of grass still in much the same unimproved condition as the whole field was in 1949, contained 2·74% C.

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The experiments each occupy about 2·8 hectares so that some variability in the carbon content of the soils would be expected within each site. Appendix Table 1 gives the % C for each block on each sampling occasion, the result is the mean of the four systems, arable, lucerne, cut grass/ley-with-N and grazed ley/grass–clover ley. The results show that on Highfield blocks 11 and 12 had most carbon whilst blocks 4 and 6 generally had least. On Fosters carbon contents were more uniform but blocks 3 and 5 on the eastern side of the experiment generally had more than those on the western side.

TABLE 1

The variability between blocks in the carbon content of the soils. Rothamsted Ley–Arable experiments, 1949–72

(% C in the 0–22·5 cm depth of soil, mean of four treatments* in each block)

Years after start of experiment	% C			Difference as % of mean
	Mean	Range	Difference	
		Highfield		
6	2·58	2·38–2·91	0·53	20
9	2·40	2·22–2·65	0·43	18
12	2·25	2·05–2·38	0·33	15
15–18	2·14	1·93–2·29	0·36	17
21–22	2·10	2·00–2·22	0·22	10
		Fosters Field		
6	1·58	1·52–1·65	0·13	8
9	1·52	1·42–1·60	0·18	12
12	1·44	1·35–1·54	0·19	13
15–18	1·50	1·38–1·58	0·20	13
21–22	1·54	1·50–1·60	0·10	6

* The four treatments were: all-arable, lucerne, cut grass/ley-with-N and grazed ley/ley-with-clover

Table 1 shows the range of carbon contents of the soils after each period and the difference between the smallest and largest amounts expressed as a percentage of the mean. The variability was larger on Highfield than on Fosters throughout the whole period of the experiments, probably because the soils on Highfield contain residues of old turf. At the last sampling, after four to eight years of continuous arable cropping, the variability when eight blocks were sampled at the same time was much less than previously. Although the variability between blocks was not large, treatment effects were small and can only be measured reliably from changes in treatments given to the same blocks of the experiment. Results from blocks 1 to 4 on both fields are little used because they were not sampled often enough.

Appendix Tables 2 and 3 give results for % C for each cropping system on each sampling occasion for blocks starting with treatment and test crops respectively. Each plot in each block was sampled and analysed separately; the results given are the mean of two replicates.

Arable and ley–arable cropping systems—blocks starting with treatment crops. Table 2 shows for each system, the % C after 6, 9, 12 and 15 years in four blocks in each experiment which started with three years of treatment crops.

On Highfield, originally permanent grass, 0·65% C was lost between the sixth and fifteenth years from soils cropped continuously with arable crops. This loss was about 25% of the organic matter still present in the sixth year. Of the 2·75% C the soils contained at the start of the experiment the loss by the fifteenth year was 28%. With the

TABLE 2

Comparison of amounts of organic carbon in the soil of the all-arable and ley and arable cropping systems after different periods. Rothamsted Ley–Arable experiments, 1949–72

(Mean of four of the blocks in each experiment which started with treatment crops)
% C in the 0–22·5 cm depth of soil (Tinsley method)

	Years after the start of the experiment				Change from 6th to 15th year	All sequences in continuous cereals since 15th year	
	6	9	12	15		After 21–22 years	Change in 6–7 years
Highfield (blocks 5, 8, 9, 12)—originally permanent grass							
Continuous arable since 1950–51	2·67	2·26	2·14	2·02	−0·65	2·00	−0·02
Rotation of 3 years arable with 3 years of:							
Lucerne	2·62	2·51	2·21	2·09	−0·53	2·10	+0·01
Cut grass/Ley-with-N	2·60	2·53	2·27	2·08	−0·52	2·10	+0·02
Grazed ley/Ley-with-clover	2·66	2·65	2·35	2·10	−0·56	2·19	+0·09
Fosters Field (blocks 5, 7, 6, 11)—originally continuous arable							
Continuous arable since 1950–51	1·48	1·41	1·34	1·36	−0·12	1·46	+0·10
Rotation of 3 years arable with 3 years of:							
Lucerne	1·57	1·50	1·34	1·40	−0·17	1·49	+0·09
Cut grass/Ley-with-N	1·62	1·62	1·44	1·48	−0·14	1·56	+0·08
Grazed ley/Ley-with-clover	1·60	1·68	1·48	1·55	−0·05	1·57	+0·02

alternate ley–arable systems the loss of organic matter was only a little less than with all-arable cropping. On average 0·54% C was lost between the sixth and fifteenth years. Thus on this soil, initially rich in organic matter, alternating three years of ley with three years of arable crops did not prevent a loss of organic carbon almost as large as that with all-arable cropping.

On Fosters Field, an old arable soil, continuing with arable cropping caused little further loss of carbon, 0·12% C which represents about 8% of that present in the sixth year. Of the 1·65% C the soils contained at the start of the experiment the loss by the fifteenth year was 17%. Although this soil initially contained less organic matter than the soil on Highfield, alternating three years of ley with three years of arable cropping did not accumulate soil organic carbon. In fact, after 15 years, there was, on average, no more organic carbon in the ley–arable soils than there was in the all-arable soil.

After 15 years the comparison of ley and arable cropping systems ceased except on blocks 1 to 4 and all plots were cropped continuously with cereals for six or seven years. Table 2 shows that there was very little further loss of carbon, less than 0·10% C, during this period on either field.

Arable and ley–arable cropping systems—blocks starting with test crops. Table 3 shows the changes in % C in four of the six blocks in each experiment which started with test crops.

On Highfield, 16% of the organic matter still present in the sixth year was lost between the sixth and eighteenth years when arable crops were grown continuously. This was a little less than on blocks which started with treatment crops because more organic

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matter had been lost from these soils by the sixth year. About 24% of the organic matter present at the start of the experiment was lost by the eighteenth year, compared with 28% lost from blocks starting with treatment crops. The loss of organic matter was almost as large under a three-year lucerne ley as it was with all-arable cropping, but was less under a grazed ley.

TABLE 3

Comparison of amounts of organic carbon in the soil of the all-arable and ley and arable cropping systems after different periods. Rothamsted Ley–Arable experiments, 1949–72

(Mean of four of the blocks in each experiment which started with test crops)
% C in the 0–22·5 cm depth of soil (Tinsley method)

	Years after the start of the experiment				Change from 6th–18th year	All sequences in continuous cereals since 18th year	
	6	9	12	18		After 21–22 years	Change in 3–4 years
Highfield (blocks 6, 7, 10, 11)—originally permanent grass							
Continuous arable since 1950–51	2·49	2·39	2·10	2·08	−0·41	1·96	−0·12
Rotation of 3 years arable with 3 years of:							
Lucerne	2·52	2·28	2·24	2·14	−0·38	2·06	−0·08
Cut grass/Ley-with-N	2·58	2·38	2·26	2·28	−0·30	2·18	−0·10
Grazed ley/Ley-with-clover	2·50	2·46	2·36	2·34	−0·16	2·22	−0·12
Fosters Field (blocks 8, 9, 10, 12)—originally continuous arable							
Continuous arable since 1950–51	1·50	1·46	1·33	1·44	−0·06	1·46	+0·02
Rotation of 3 years arable with 3 years of:							
Lucerne	1·52	1·44	1·41	1·47	−0·05	1·54	+0·07
Cut grass/Ley-with-N	1·62	1·48	1·50	1·60	−0·02	1·62	+0·02
Grazed ley/Ley-with-clover	1·60	1·50	1·50	1·65	+0·05	1·61	−0·04

TABLE 4

Percentage increases in organic carbon due to ley treatments compared to an all-arable rotation after different periods. Rothamsted Ley–Arable experiments, 1949–72

(Mean of eight blocks in each experiment for 6, 9 and 12 years, four blocks for 15 and 18 years)

Treatment sequence	Years after the start of the experiment				
	6	9	12	15	18
Highfield originally permanent grass					
Arable % C	2·58	2·32	2·12	2·02	2·08
Percentage increase in organic carbon over that in the all-arable					
Lucerne	−0·4	+3·4	+4·7	+3·5	+2·9
Cut grass/Ley-with-N	+0·4	+6·0	+6·6	+3·0	+9·6
Grazed ley/Ley-with-clover	0	+10·3	+11·3	+4·0	+12·5
Fosters Field originally continuous arable					
Arable % C	1·49	1·44	1·34	1·36	1·44
Percentage increase in organic carbon over that in the all-arable					
Lucerne	+3·4	+2·1	+3·0	+2·9	+2·1
Cut grass/Ley-with-N	+8·7	+7·6	+9·7	+8·8	+11·1
Grazed ley/Ley-with-clover	+7·4	+10·4	+11·2	+14·0	+14·6

On Fosters Field too, the results from blocks starting with test crops were very similar to those starting with treatment crops. Continuous arable cropping caused a small loss, less than 5%, of the organic matter present in the sixth year; there was no change in the amount of organic matter when results from the three systems which included leys were averaged.

After 18 years the comparison of ley and arable systems ceased on these blocks and cropping continued with cereal crops. Results in Table 3 confirm those in Table 2, there was very little further change in the carbon content of the soils.

Changes caused by leys compared with all-arable cropping. Irrespective of whether the blocks started with treatment or test crops the effect on the organic matter content of the soil was much the same especially after the first six or nine years (Tables 2 and 3). The results are combined in Table 4 which shows the effects on soil organic carbon of three ley–arable systems and compares them with continuous arable. Each soil when cropped with a ley and arable system always contained more organic matter than the same soil continuously in arable and the carbon analyses were always in the order: arable < lucerne < cut grass/ley-with-N < grazed ley/ley-with-clover. Differences between the effects of the treatments are, however, small. Lucerne leys increased organic matter less than 5% whilst the largest effect of grazed ley was only 15%. Equally important moreover, is the evidence these results provide that the effect of leys is not greater on Fosters, the old arable field, than on Highfield, long in permanent grass. It is also interesting that the results in Table 4 show no appreciable change in the size of the effects of the leys with increasing time.

Fig. 1 shows how the organic carbon changed with time with the various cropping systems. The figure shows clearly that, although the ley–arable soils always had more organic matter than the all-arable soils the extra was small. The very small increase in organic matter on Fosters after 18 years may be an effect of the change in sampling depth as mentioned in the Appendix. Fig. 1 further shows that if the organic matter on Highfield had continued to decrease after the first 12 years at the same rate as before, then the all-arable soils would have contained little more organic matter than those on Fosters after 24 years. However, the rate of loss decreased considerably between the sixth and twenty-second year and the all-arable soils on Highfield still contained after 22 years, about 0·5% C more than those on Fosters. Blocks 1 to 4 in both experiments are to continue with present treatments unchanged to see what further changes take place. Ploughing some old sward, adjacent to one of the blocks of the Highfield experiment in spring 1959 when the soil contained 3·00% C, shows that such changes may take many years. The land has been fallowed each year and, without any additions of organic matter as root residues from crops, in 1971 there was still 1·65% C, slightly more than in the all-arable soil on Fosters.

Reseeded and permanent grass. After grazing ceased, reseeded (R) and permanent (G) grass plots were split to compare (1) grass–clover without N (Rc and Gc treatments) and (2) grass-with-N (Rn and Gn treatments). Samples were taken only when the other plots in each block were sampled so that there are not always results for each block every three years. However, if it is assumed that the rate of change was about the same on all blocks, results can be derived for each three-year period. Such results are shown by open circles in Fig. 2.

Permanent grass. Fig. 2 shows changes in organic carbon under permanent grass on Highfield and the results for four pairs of blocks show how very similar the changes were on all blocks. Before 1949 part of the field was used for an experiment on the residual

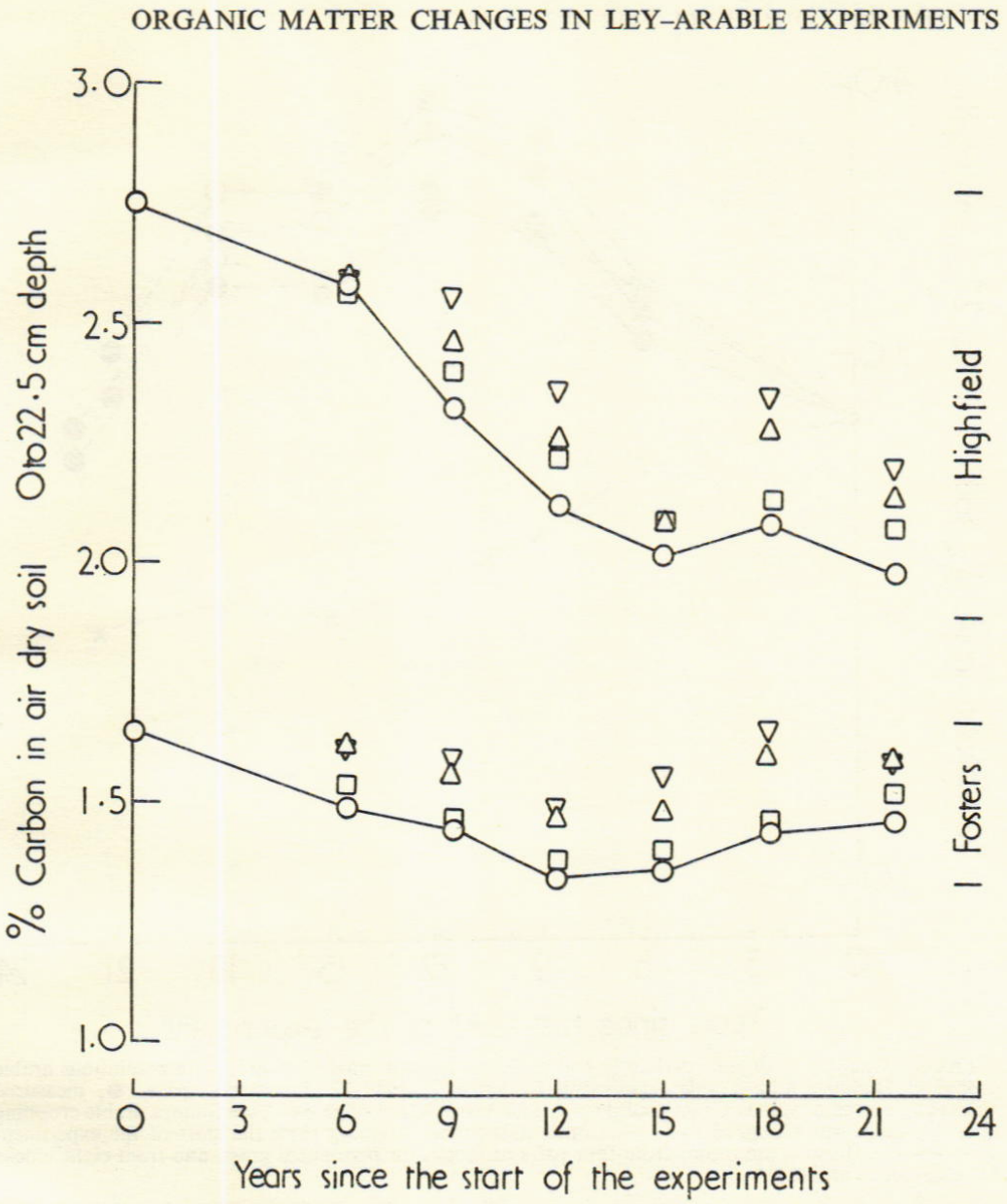

FIG. 1. Changes in organic carbon in soil caused by ley and arable cropping systems. Rothamsted Ley–Arable experiments, 1949–72. Continuous arable cropping, ○; ley–arable cropping systems, lucerne, □; cut grass/ley-with-N, △; grazed ley/ley-with-clover, ▽. (Results are means from eight blocks for each experiment for 6, 9, 12 and 21/22 years and from four blocks for 15 and 18 years.)

value of animal feedingstuffs, stocking rates were small and management not intensive. With increased fertiliser used and more intensive grazing by sheep during the first 12 years of the ley–arable experiment organic matter increased, on average by 1% C. The shapes of the curves in Fig. 2 suggest that the rate of increase was diminishing as a new equilibrium between accumulation and decomposition of organic matter was established. The change of management to cutting the leys caused a loss of about 0·25% C and apparently a new equilibrium was established at about 3·5% C in the soil. After 18 years this permanent grass was ploughed and cropped as the all-arable rotation. Fig. 2 shows there was a loss of organic matter. After three or four years of arable cropping the soil

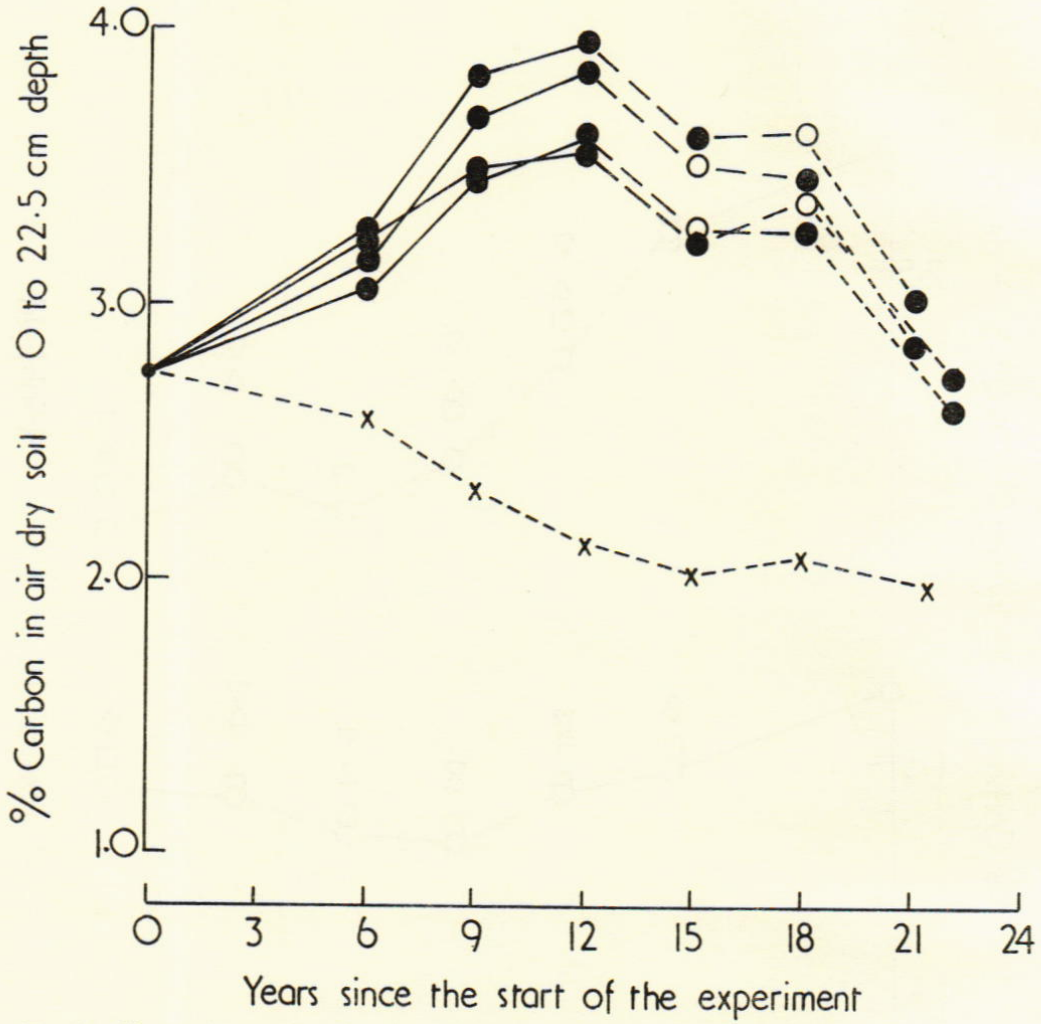

FIG. 2. Changes in organic carbon in soil under permanent grass compared with continuous arable cropping. Highfield Ley–Arable experiment, Rothamsted, 1949–72. Permanent grass, ●, measured values; ○, estimated values. Grass grazed ——, grass cut at silage stage — —, continuous arable cropping after the grass was ploughed – – – – –. Continuous arable cropping since the start of the experiment ×– – – – –×. (Results are means from four pairs of blocks for permanent grass, and from eight blocks for continuous arable.)

had slightly more organic matter than at the start of the experiment and about 1% C more than in those soils which grew arable crops continuously for 21 years.

The reseeded grass was treated in two different ways. On six blocks it was grazed for 12 or 15 years, then ploughed and cropped as the all-arable system in each block. On the other six blocks it was grazed for 12 or 13 years before the comparison between the two methods of managing cut grass, Rc and Rn, was introduced. This cut grass lasted five or six years before it also was ploughed on four blocks and the plots were cropped continuously with arable crops. Fig. 3 shows the changes in organic carbon with reseeded grass. Fig. 3a shows that with grazing, organic carbon increased, and after 12 years there was slightly more than 3% C on Highfield and 2% C on Fosters. The indication from the shapes of the curves is that organic matter on the old arable soil (Fosters) was

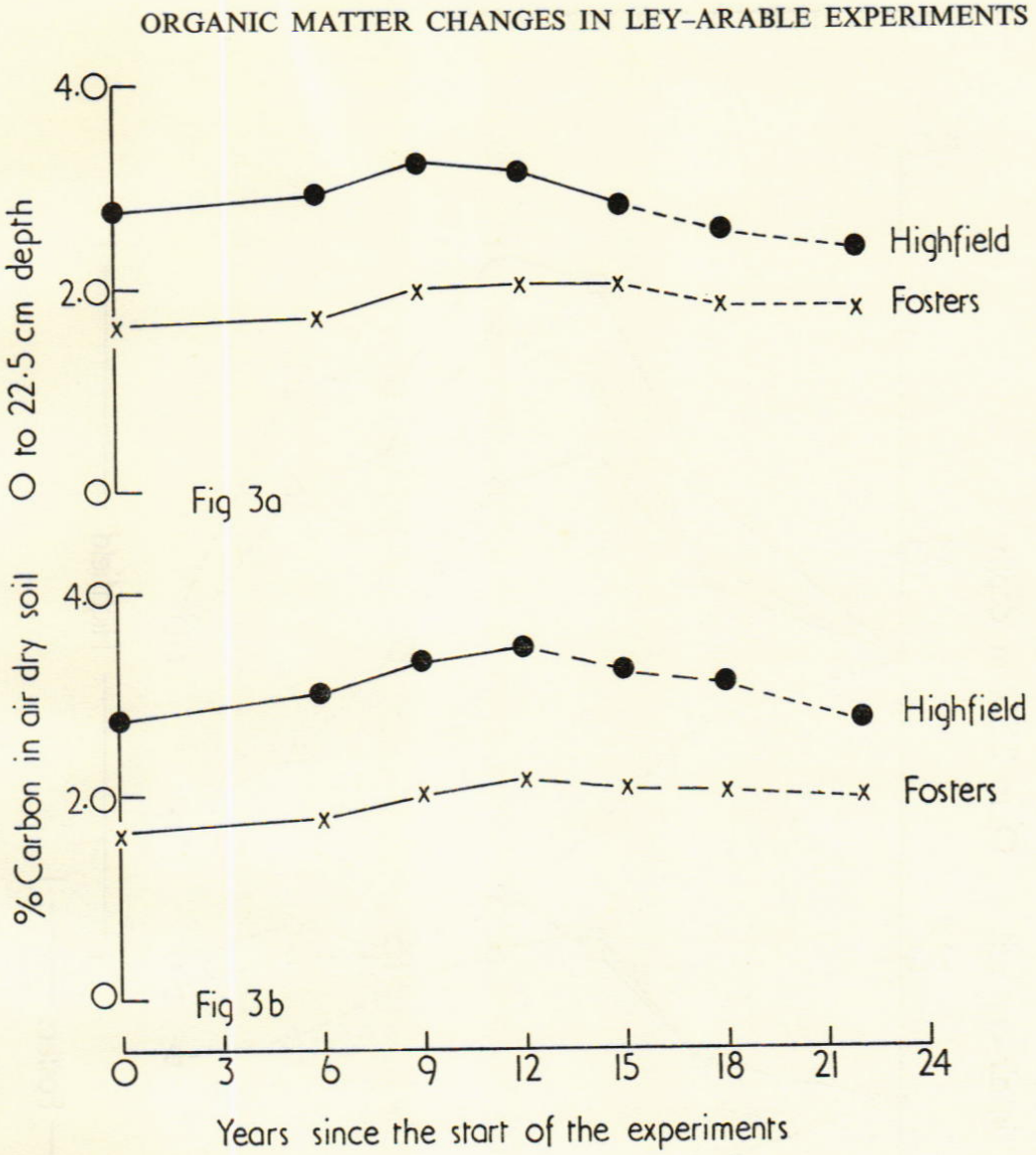

FIG. 3. Changes in organic carbon in soil under the reseeded grass. Rothamsted Ley–Arable experiments, 1949–72. Highfield, ●; Fosters, ×.

FIG. 3a. Grass grazed for 15 years then ploughed and arable crops grown continuously for 6 to 7 years. Grass grazed ——; all-arable cropping, – – – – –.

FIG. 3b. Grass grazed for 12 years then cut at silage stage for six years, then ploughed and arable crops grown continuously for three to four years. Grass grazed, ——; grass cut — —; all arable cropping, – – – – –. (Results are means from all 12 blocks in both experiments.)

increasing so slowly that it would take many years to equal the amount present in soil long in permanent grass (Highfield). When the reseeded grass was ploughed the amount of organic matter decreased. During eight to ten years of continuous arable cropping about 25% of the organic matter on Highfield was lost, whilst on Fosters, where there was much less initially, only about 15% was lost.

Figure 3b shows the effect of the change to cutting the reseeded grass. The results during the first 12 years confirm the previous observation (Fig. 3a) that there was no rapid accumulation of organic matter on Fosters. There is some indication that the change from grazing to cutting leys caused some loss of organic matter as new and

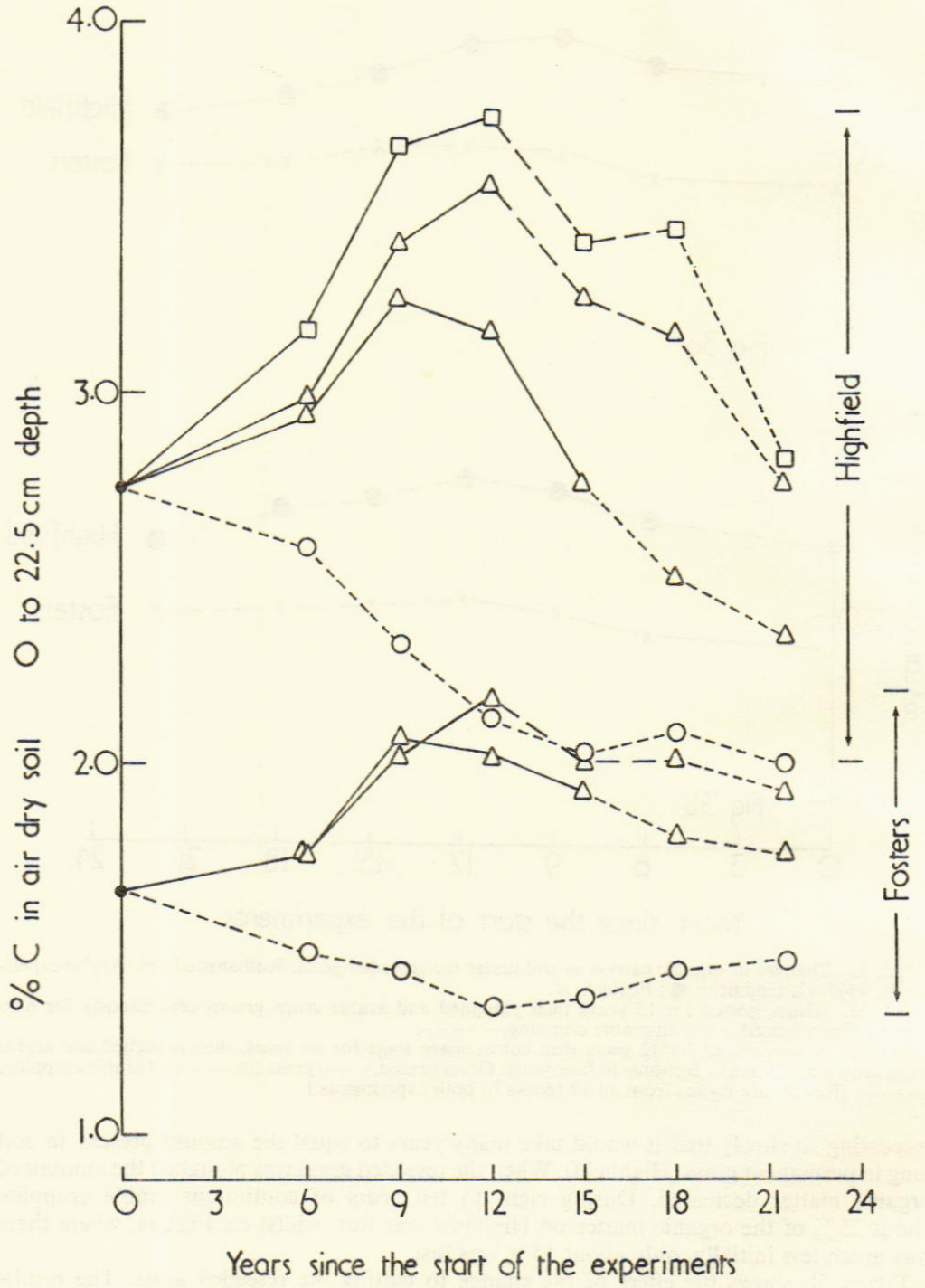

FIG. 4. Changes in organic carbon in soil under continuous arable cropping, ○; reseeded grass, △ and permanent grass, □. Rothamsted Ley–Arable experiments, 1949–72. Grass grazed ——, grass cut at silage stage — —, arable crops grown continuously – – – –. (Results are means from blocks 5 to 12 inclusive in both experiments.)

smaller equilibrium values were established between accumulation and decomposition, on both fields. This confirms the results from the permanent grass plots on Highfield. These results differ from those obtained with three-year leys where it was not possible to detect any effect due to the change from grazing to cutting leys at silage stage.

Comparison between continuous arable and reseeded and permanent grass. Fig. 4 compares the changes in % C in the all-arable system with those under reseeded and permanent grass on both Highfield and Fosters. The results are from blocks 5 to 12 inclusive on both fields. Comparisons are best made with the results from plots growing arable crops continuously on Fosters. After a small decrease in organic matter in the first few years of the experiment the organic carbon content remained unchanged at 1·4–1·5% C. Whilst the reseeded grass remained unploughed organic matter in the soil increased, to 2·1% C. Thus after 12 years there was 50% more organic matter in these soils than in those growing arable crops continuously. After ploughing the reseeded grass, arable crops were grown for nine years; there was still 0·4% C more in these soils (Fig. 4) than in those with continuous arable even at the end of the nine years.

Fig. 4 also shows that on the old arable soil of Fosters Field, when the reseeded grass was grazed, organic carbon increased during the first 12 years and then it equalled the amount to which the old grassland soil on Highfield decreased when arable crops were grown continuously. However, during the next nine years, with continuous arable cropping on both soils, organic matter decreased more after the reseeded grass on the old arable soil than on the soil originally richer in organic matter.

Fig. 4 shows that even on the soil initially well supplied with organic matter, improved management of the grass increased the organic carbon in the soil. It is interesting that organic matter in the soil on Highfield was always less under reseeded grass than under permanent grass. The difference must be because organic matter was lost when the permanent grass was ploughed and the soil cultivated before resowing. Subsequently, when both reseeded and permanent grass were grazed, organic matter increased at the same rate with both treatments.

On Highfield organic matter was lost during the nine years of arable cropping that followed the 12 years of reseeded grass but these soils still contained more organic matter than those where short leys alternated with arable crops. As the same result was found on Fosters this suggests that soil organic matter will be increased and maintained better by a long period in grass, 9 or 12 years, followed by an equally long period of arable cropping than by alternating three-year leys with three years of arable crops.

Part 2. The Woburn Ley–Arable experiment, 1938–69

The experiment

In 1938, when the experiment started, it was thought that alternating leys with arable crops would have greater benefit on the lighter rather than the heavier soil on the Woburn farm. The light soil is classified as Cottenham Series, which is a sandy loam developed in drift over Lower Greensand. The history of the chosen site, Series D, Stackyard Field, was well-known as experiments had been made there since 1876. Initially called Rotation IV, the site was one of four blocks farmed on a four-course rotation of roots, barley, seeds and wheat. In each block there were four plots which tested the residual manurial value of cake and corn fed to animals in yards, or on the land, and compared their effects with those of NPKMg fertilisers supplying the same amount of nutrients as in the manure made from the two feedingstuffs. In 1911 this experiment was greatly modified but Series D continued in a four-course rotation until 1936. In 1937 the site was fallowed prior to

the start of the Ley–Arable experiment in 1938. The rotation experiment was well-manured between 1876 and 1884; between 1885 and 1902 there was a deliberate attempt to decrease fertility and from 1903 to 1936 manuring was average for the period.

The Woburn experiment was simpler than those at Rothamsted, which undoubtedly benefited from experience gained at Woburn. In retrospect, it is unfortunate that the Woburn experiment did not include a test of a long ley or reseeded grass. Four contrasted cropping systems, each lasting three years, were compared, and their effects were measured from the yields of two arable test crops that followed. Three crops were used as first test crops: potatoes, 1938–55, sugar beet 1956–67 and barley 1968–69. The second test crop was always barley. The treatment cropping systems were:

1. Three-year arable with roots (Ar): potatoes, cereal, root crop.
2. Three-year arable with hay (Ah): potatoes, cereal, one-year seeds-hay.
3. Three-year lucerne (Lu): lucerne cut for hay, after 1963 lucerne was replaced by sainfoin.
4. Three-year grass–clover ley (L): the ley was given only a little N and was grazed by sheep.

The experiment had five blocks, one for each phase of the five-year cycle of treatment and test crops, there was no replication. Each block was divided into eight plots to compare the effects of repeating each of the four cropping systems either (i) always on the same plot, or (ii) following one another on each plot, the arable and ley systems alternating. The experiment therefore included plots where treatment sequences were continuous and others where the sequences alternated. For example, three years of treatment crops and two years of test crops, potatoes (P) and barley (B) succeeded one another as follows:

Treatment sequences continuous	Ar	P B	Ar	P B	Ar	P B	Ar	P B
	Lu	P B	Lu	P B	Lu	P B	Lu	P B
Treatment sequences alternated	Lu	P B	Ar	P B	L	P B	Ah	P B
	Ar	P B	Lu	P B	Ah	P B	L	P B

In addition a test of farmyard manure (FYM), applied to the first test crop, was included. The amount applied was 38 t FYM/ha; the test was made on half plots.

Starting in 1938, each block was phased in as follows:

	Block				
Year	3	5	4	2	1
1938	1Tr	2Ts	1Ts	Barley	Barley
1939	2Tr	1Tr	2Ts	1Ts	Hay/Kale
1940	3Tr	2Tr	1Tr	2Ts	1Ts
1941	1Ts	3Tr	2Tr	1Tr	2Ts
1942	2Ts	1Ts	3Tr	2Tr	1Tr

1, 2, 3: 1st, 2nd, 3rd year; Tr, treatment crop; Ts, test crop

Boyd (1968) summarised yield results to 1967. For details of seed mixtures, manuring and management see Rothamsted Experimental Station (1970).

Results

The methods of sampling and analysis are given in the Appendix. Before the start of the experiment in 1938 the average carbon content of the soil of the five blocks was 1·02% C. The Woburn experiment occupies about 1·6 ha, less than either Rothamsted experiment. However, the site is on a slope with block 1 at the top and 5 at the bottom. Table 5 shows how the carbon content varied between blocks at the start of the experiment and after

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18, 23 and 28 years. Block 4 always had the most carbon and blocks 1 and 2 least. Treatments which increased or decreased soil organic carbon always had the same effect on the different blocks. However, all treatment means in this paper are averages of all five blocks because differences in soil carbon between blocks were as great as, or greater than, the effect of the treatments.

TABLE 5

The variability between blocks in the carbon content of the soils. Woburn Ley–Arable experiment, 1938–69

(% C in the 0–25 cm depth. Mean of all plots in each block)

	Block					Mean	Range	Difference	Difference as % of mean
	1	2	3	4	5				
1st year 1938	0·97	0·93	1·03	1·15	1·01	1·02	0·93 to 1·15	0·02	22
Plots where treatment sequences were continuous									
After 18 years	0·89	0·94	1·10	1·22	1·11	1·05	0·89 to 1·22	0·33	31
After 23 years	0·88	0·93	1·02	1·22	1·15	1·04	0·88 to 1·22	0·34	33
After 28 years	0·96	0·95	1·02	1·22	1·08	1·05	0·95 to 1·22	0·27	26
Plots where treatment sequences were alternated									
After 18 years	0·98	0·96	1·10	1·14	1·08	1·05	0·96 to 1·14	0·18	17
After 23 years	0·99	0·94	1·00	1·13	1·15	1·04	0·94 to 1·15	0·21	20
After 28 years	1·04	0·96	1·01	1·18	1·06	1·05	0·96 to 1·18	0·22	21

Appendix Tables 4 and 5 give the % C in the soil of each plot after 18, 23 and 28 years where treatment sequences were continuous and alternating respectively. On those plots where treatment sequences alternated, the results from the same group of plots are always averaged and given under the heading of the treatment sequence with which the plots started in 1938–42. In Appendix Table 5 the treatment, ley or arable, from which the samples were taken is shown.

TABLE 6

Comparison of amounts of organic carbon in the soil of the all-arable and ley and arable cropping systems after different periods. Woburn Ley–Arable experiment, 1938–69

Plots where treatment sequences were continuous
(% C in the 0–25 cm depth of soil (Tinsley method))

	Years after the start of the experiment			Change from 18th to 28th year
	18	23	28	
Plots without FYM				
Rotation of 2 years arable test crops with 3 years of:				
Arable-with-roots	0·91	0·90	0·88	−0·03
Arable-with-hay	0·98	0·94	0·95	−0·03
Lucerne	1·00	0·96	0·95	−0·05
Grazed ley	1·10	1·10	1·13	+0·03
Plots with FYM				
Rotation of 2 years arable test crops with 3 years of:				
Arable-with-roots	0·99	0·97	0·98	−0·01
Arable-with-hay	1·07	1·07	1·04	−0·03
Lucerne	1·14	1·10	1·13	−0·01
Grazed ley	1·21	1·28	1·32	+0·11

Changes in each system between the eighteenth and twenty-eighth years. Table 6 shows for each cropping system the % C after 18, 23 and 28 years where treatment sequences were continuous. Between the eighteenth and twenty-eighth years only 0·03% C was lost during the ten years in the all-arable systems where FYM was not given. This loss, which occurred whether a root crop or a one year seeds–hay was taken in the third treatment year, was only 3% of the organic matter still present in the eighteenth year. Where FYM was given once in five years, the losses were the same or slightly less. Table 6 also shows that organic matter increased very little (about 3%) when a three-year grazed ley alternated with two years of arable crops not given FYM, but more (about 11%) when FYM was given.

Under the lucerne ley, carbon in the soil slightly decreased and the effect of the lucerne on soil organic matter was, therefore, more like that of all-arable cropping than of grazed ley. Similar results were obtained in the Rothamsted experiments (see page 135).

The changes in organic carbon in the soil due to the treatments took place during all the 28 years of the experiment but the effects were not large. About 11% of the original amount of soil organic matter was lost from the all-arable systems and about 14% was gained with the grazed ley when no FYM was given.

TABLE 7

Comparison of amounts of organic carbon in the soil of the ley–arable cropping systems after different periods. Woburn Ley–Arable experiment, 1938–69

Plots where treatment sequences were alternated
(% C in the 0–25 cm depth of soil (Tinsley method))

Plots starting 1938–42 with:	Years after the start of the experiment			Change from 18th to 28th year
	18	23	28	
	Plots without FYM			
Arable-with-roots	1·08	1·01	1·04	−0·04
Arable-with-hay	0·95	0·95	0·97	+0·02
Lucerne	0·97	0·94	0·93	−0·04
Grazed ley	0·95	1·02	0·96	+0·01
	Plots with FYM			
Arable-with-roots	1·21	1·16	1·19	−0·02
Arable-with-hay	1·07	1·06	1·10	+0·03
Lucerne	1·08	1·04	1·02	−0·06
Grazed ley	1·09	1·18	1·19	+0·10

Table 7 shows for each cropping system the % C in soil after 18, 23 and 28 years where treatment sequences were alternated. The results confirm those given in Table 6 and show that changes in soil organic carbon between the eighteenth and twenty-eighth years were very small. The changes are more variable however because a loss with all-arable cropping could be compensated in part by a gain with grazed ley. Results from the continuous and alternating treatment sequences are, therefore, discussed separately.

Changes caused by the treatments compared with arable-with-roots. Table 8 gives the increases in organic carbon due to ley and arable-with-hay systems compared with continuous arable-with-roots cropping. There was least organic matter with the arable-with-roots system both without and with FYM applied at 38 t/ha once every five years. Increases from the other three cropping systems at any comparable time were small. Without FYM, soil carbon increased by less than 10% under lucerne and arable-with-hay rotations; but by as much as 30% under grazed ley. It was only under grazed

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TABLE 8

Increases in organic carbon due to ley and arable-with-hay cropping systems compared to an all-arable rotation, Woburn Ley–Arable experiment, 1938–69

Plots where treatment sequences were continuous
(% C in 0–25 cm depth soil)

Rotation	Years after the start of the experiment 18	23	28
	Plots without FYM		
Arable-with-roots % C	0·91	0·90	0·88
Percentage increase in organic carbon compared with arable-with-roots			
Arable-with-hay	8	4	8
Lucerne	10	7	8
Grazed ley	21	22	28
	Plots with FYM		
Arable-with-roots % C	0·99	0·97	0·98
Percentage increase in organic carbon compared with arable-with-roots			
Arable-with-hay	8	10	6
Lucerne	15	13	15
Grazed ley	22	32	35

ley that organic matter increased throughout the experiment. Where FYM was also applied, the increases in organic matter due to leys were larger than without FYM; the increase was 15% with lucerne and as much as 35% with grazed ley.

The changes in soil carbon caused by alternating the treatment sequences are best compared with the % C in the continuous arable-with-roots. Table 9 shows the results.

TABLE 9

Changes in organic carbon due to alternating ley and arable cropping systems compared with continuous arable, Woburn Ley–Arable experiment, 1938–69

Plots where treatment sequences were alternated
(% C in 0–25 cm depth soil)

	Years after the start of the experiment 18	23	28
	Plots without FYM		
Continuous arable-with-roots since 1938, % C	0·91	0·90	0·88
Percentage increase in organic carbon compared with arable-with-roots			
Plots starting in 1938–42 with:			
Arable-with-roots	19	12	18
Arable-with-hay	4	6	10
Lucerne	6	4	6
Grazed ley	4	13	9
	Plots with FYM		
Continuous arable-with-roots since 1938, % C	0·99	0·97	0·98
Percentage increase in organic carbon compared with arable-with-roots			
Plots starting in 1938–42 with:			
Arable-with-roots	22	20	21
Arable-with-hay	8	9	12
Lucerne	9	7	4
Grazed ley	10	22	21

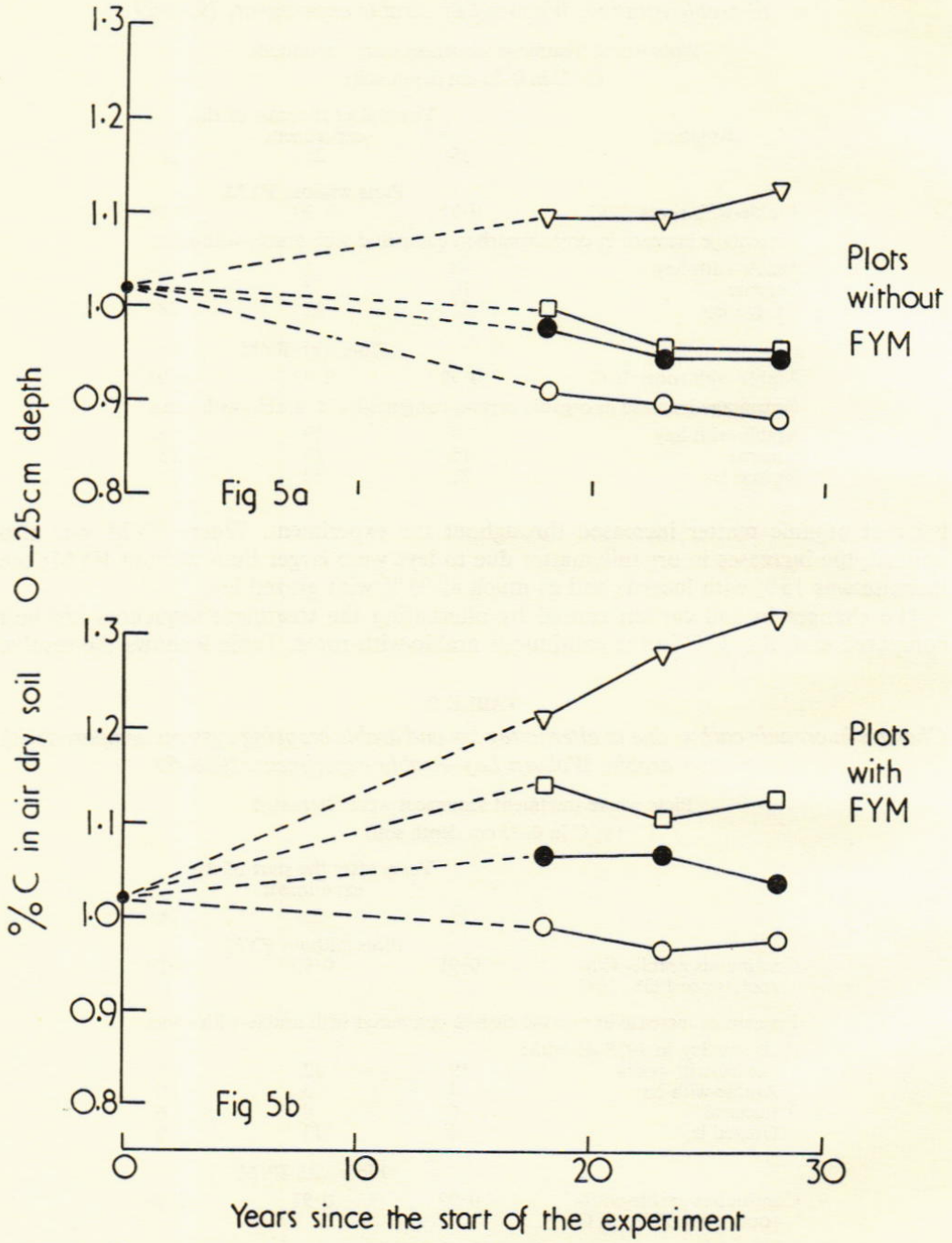

FIG. 5. Changes in organic carbon in soil caused by ley and arable cropping systems. Woburn Ley–Arable experiment, 1938–69. Plots where treatment sequences were continuous.
FIG. 5a. Plots not given farmyard manure (FYM).
FIG. 5b. Plots given farmyard manure, 38 t/ha once every five years.
Cropping systems tested: arable-with-roots, ○; arable-with-hay, ●; lucerne, □; grazed ley, ▽.

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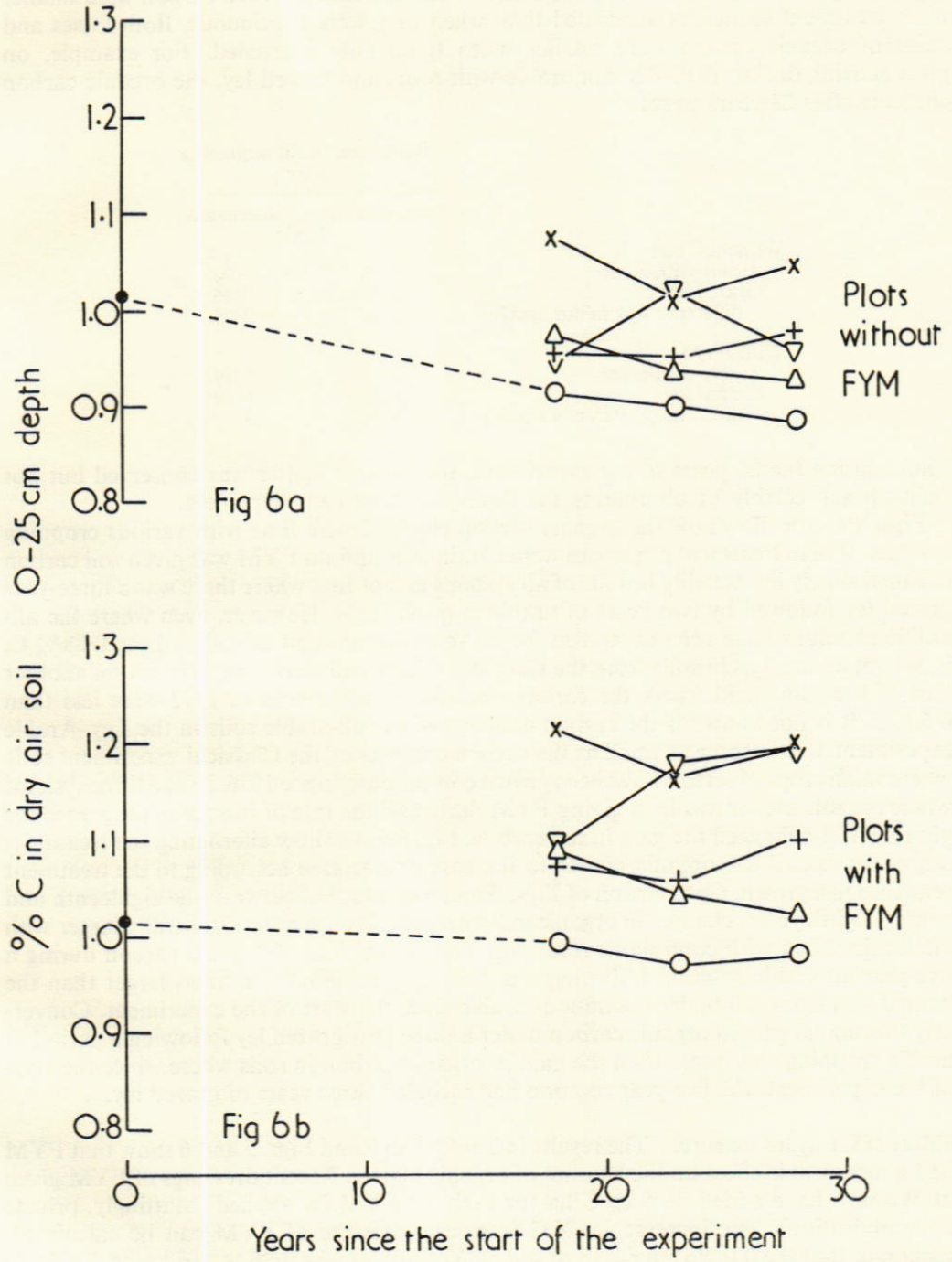

FIG. 6. Changes in organic carbon in soil caused by alternating the treatment sequences compared to the continuous arable-with-roots system. Woburn Ley–Arable experiment, 1938–69.

FIG. 6a. Plots not given farmyard manure (FYM).

FIG. 6b. Plots given farmyard manure, 38 t/ha once every five years.

Treatment sequences that started with: arable-with-roots, ×; arable-with-hay, +; lucerne, △; grazed ley, ▽. Continuous arable-with-roots system, ○.

Comparing the results in Tables 8 and 9 shows that the effects on soil carbon were smaller when treatment sequences alternated than when they were continuous. Both losses and gains of organic carbon were smaller when treatments alternated. For example, on plots starting during 1938–42 with arable-with-roots and grazed ley, the organic carbon contents after 28 years were:

	Where treatment sequences were	
	continuous	alternated
	% C	
Without FYM		
Arable-with-roots	0·88	1·04
Grazed ley	1·13	0·96
difference (ley minus arable)	0·25	−0·08
With FYM		
Arable-with-roots	0·98	1·19
Grazed ley	1·32	1·19
difference (ley minus arable)	0·34	0

Thus, during the 28 years of the experiment, the organic matter was conserved but not built up appreciably by alternating the three-year treatment sequences.

Figs. 5 and 6 show how the organic carbon changed with time with various cropping systems. Where treatment sequences were continuous and no FYM was given soil carbon declined slowly but steadily in soils of all systems except that where there was a three-year grazed ley followed by two years of arable crops (Fig. 5). However, even where the all-arable rotations have been continued for 28 years the amount of soil carbon, 0·88% C, is not yet as small as in soils from the Classical Wheat and Barley experiment on another part of the same field where the carbon contents of some soils in 1972 were less than 0·6% C. It is not known if the carbon contents of the all-arable soils in the Ley–Arable experiment will become as small as the carbon contents of the Classical experiment soils where small crops of cereals have been grown continuously since 1876. In the three systems where organic matter was lost, giving FYM decreased the rate of loss; with the grazed ley giving FYM enhanced the gain in soil carbon. Fig. 6 shows how alternating the treatment sequences caused the organic matter to increase or decrease according to the treatment sequence just grown. Comparison of Figs. 5 and 6 shows that between the eighteenth and twenty-eighth years, changes in organic matter during five years were generally larger with alternating than with continuous rotations. The annual loss of organic carbon during a five-year all-arable rotation following a grazed ley was about five times larger than the annual loss from soil under continuous arable since the start of the experiment. Conversely the annual gain in organic carbon under a three year grazed ley following a period of arable cropping was larger than the gain in organic carbon in soils where, since the start of the experiment, the five-year rotation had included three years of grazed ley.

Effect of farmyard manure. The results in Tables 6 to 9 and Figs. 5 and 6 show that FYM had a measurable effect on the amount of organic matter. Recent dressings of FYM given at Woburn have added 86·6 kg C/ha for each 1 t FYM/ha applied (Mattingly, private communication). The increase in % C from any dressing of FYM can be calculated, assuming that the 0 to 25 cm depth of soil at Woburn weighs $3{\cdot}36 \times 10^6$ kg/ha. Table 10 shows increases in % C calculated from the amounts of FYM added after 18, 23 and 28 years, the measured increases as % C, and as percentages of the calculated amounts applied in FYM. All comparisons show that the amount of extra organic matter accumulated from FYM did not increase with time and, where treatment sequences were continuous, the increase in organic matter depended only on the cropping system. With

TABLE 10

Effect of farmyard manure on the amount of soil organic carbon. Woburn Ley–Arable experiment, 1938–69

Years after start of experiment	Calculated increase in organic carbon % C	Increase in % C as measured				Measured increase as percentage of calculated			
		Rotation at the start of the experiment				Rotation at the start of the experiment			
		Arable-roots	Arable-hay	Lucerne	Grazed ley	Arable-roots	Arable-hay	Lucerne	Grazed ley
		Plots where treatment sequences were continuous							
18	0·294	0·078	0·087	0·145	0·117	27	30	50	40
23	0·392	0·070	0·124	0·149	0·186	18	32	38	48
29	0·489	0·098	0·091	0·176	0·193	20	19	36	40
					Mean	22	27	41	43
		Plots where treatment sequences were alternated							
18	0·294	0·134	0·122	0·113	0·143	46	41	38	49
23	0·392	0·157	0·109	0·106	0·157	40	28	27	40
28	0·489	0·150	0·127	0·094	0·235	31	26	19	48
					Mean	39	32	28	46

the two arable systems, where the land was ploughed and cultivated every year, only about a quarter of the organic matter added as FYM remained in the soil. Where lucerne and grazed leys were grown and land was not ploughed for the three treatment years the increase was larger, about 40% of the added organic matter. Where treatment sequences were alternated arable and ley treatments had similar effects. When averaged over the three periods, the measured increases in % C, as percentages of the calculated amounts applied in FYM, ranged from 28 to 45%.

Part 3. Comparisons between and conclusions from the experiments

Results from the ley–arable experiments at Woburn and Rothamsted show the effects different cropping systems had on soil organic matter after more than 20 years. Fig. 7 summarises the changes in organic carbon with time for some treatments in all three experiments. There are two important conclusions:

1. There is effectively no overlap between the results for the three experiments, each occupies a separate part of the figure with the exception of the reseeded grass treatment on Fosters Field. This treatment, if it had continued, might have accumulated more organic matter and eventually had more than the all-arable rotation on Highfield.
2. On the light soil at Woburn no cropping system increased organic matter rapidly. A five-year cycle of three years grazed ley followed by two years arable crops conserved organic matter but did not appreciably increase it, except when five dressings of FYM, each of 38 t/ha, were also given every fifth year to the first test crop. Even after 28 years with this treatment, there was less organic matter in the Woburn soils than in soils from the all-arable rotation on Fosters Field at Rothamsted.

Fig. 7 shows that in the all-arable rotations at Woburn there was a small but continuing loss of organic carbon. However, since 1938, this loss was less than on the Classical site on the same field where cereals were grown continuously. There were similar results at Rothamsted. There was little change in organic matter with the all-arable rotation on Fosters Field, and the amount is still larger than on Broadbalk where fertilisers only are

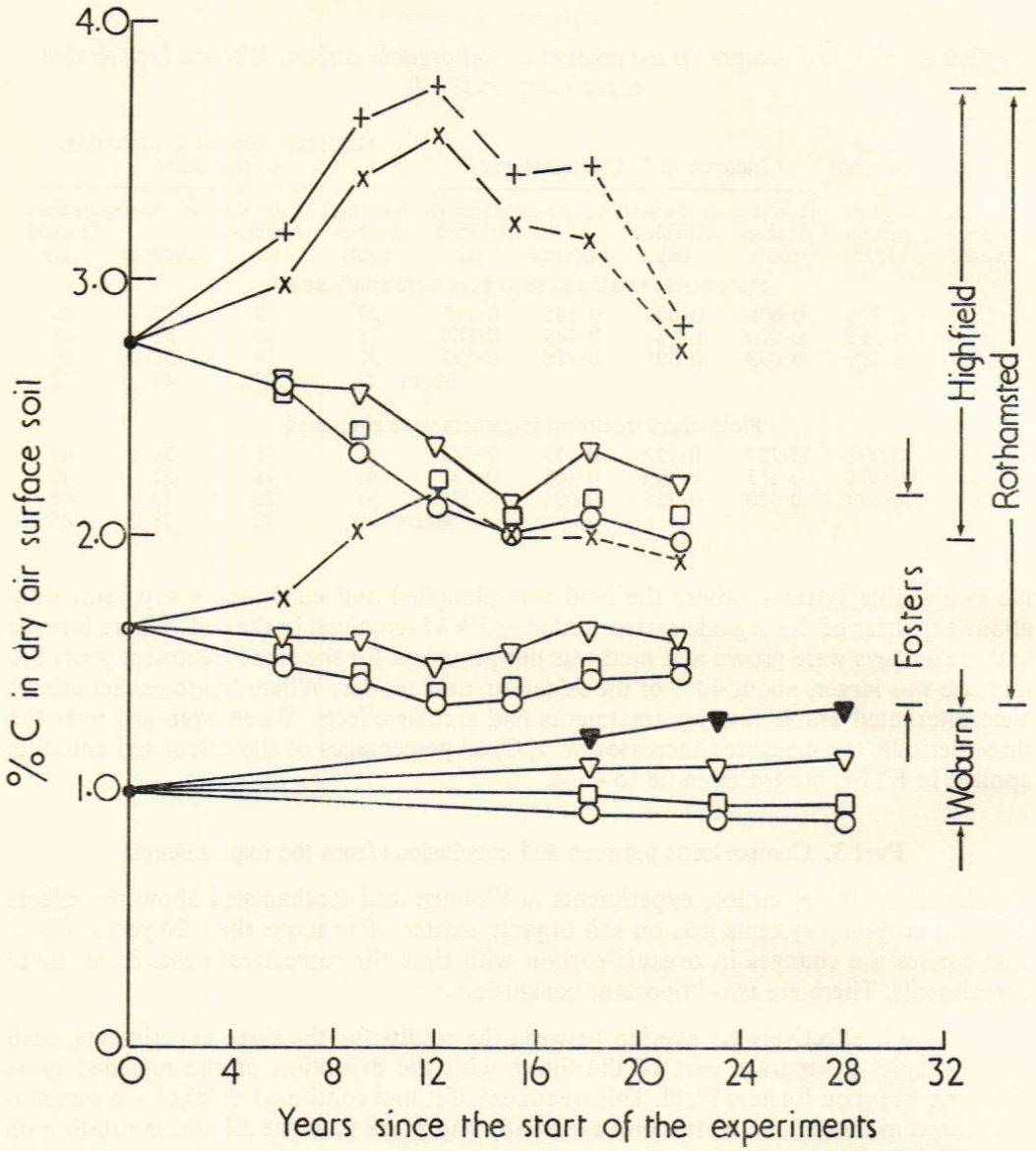

FIG. 7. Changes in organic carbon in soil caused by some of the cropping systems tested in three ley–arable experiments. (i) Woburn, where treatment sequences were continuous, 1938–69; (ii) Fosters field, Rothamsted, 1949–72; (iii) Highfield, Rothamsted, 1949–72. Continuous arable cropping, ○; ley–arable systems, lucerne, □; grazed ley, ▽; grazed ley with farmyard manure, ▼; grass for many years; reseeded grass, ×; permanent grass, +; these two grass treatments were divided into grass grazed, ——; grass cut, — —; arable cropping after grass ploughed, – – – – –.

given to winter wheat grown continuously. We intend to see whether a rotation of arable crops conserves organic matter better than continuous cereal growing. Much organic matter was lost during the all-arable rotation on Highfield where there was much at the start of the experiment. However, the rate of loss decreased appreciably over the last six years and after 22 years the all-arable soils on Highfield still contained about 0·5% more carbon than soils on Fosters.

Of the ley–arable systems tested, a grazed ley increased organic matter most compared with the amount maintained in soil under an all-arable rotation, and proportionally

the effect was larger at Woburn than at Rothamsted, possibly because the leys lasted for three years of the five-year cycle at Woburn. Cut grass leys, tested only at Rothamsted, gave smaller increases in organic matter than grazing leys. In all three experiments there were unexpectedly small increases in soil organic matter under lucerne leys. After three years of lucerne, soil organic matter was still larger than under an all-arable rotation. On average, three-year leys increased soil organic matter by not more than 10% compared with the amounts present in continuous arable rotations.

Grass that remained unploughed for longer than three years was tested only at Rothamsted but Fig. 7 shows that soil organic carbon increased by more than 10%. The amount of the increase depended on the way the grass was managed; it was greater when the grass was grazed than when it was cut at silage stage. The increases in soil organic matter were not only larger when the grass was unploughed for 9 to 12 years, but Figs. 1 and 4 show that more organic matter remained after nine years of continuous arable cropping that followed than when three years of ley and three years of arable crops alternated.

Summary

1. Changes in soil organic carbon were measured in three experiments made to compare ley–arable with all-arable cropping systems and to test their effects on succeeding arable crops. Two experiments were at Rothamsted on soils of the Batcombe series, one at Woburn on soil of the Cottenham series.

2. Treatment cropping was for three years, test cropping was for two years at Woburn and three years at Rothamsted. Test crops included winter wheat, barley, potatoes and sugar beet.

3. At Rothamsted treatments included 'reseeded' and 'permanent' grass which lasted longer than three years. Some of this grass was ploughed after 9 or 12 years and its effects tested by arable crops grown for nine years.

4. The leys were lucerne and cut grass (Rothamsted only), both cut at silage stage, and grazed ley. At Rothamsted grazing was phased out and starting in 1962 a grass–clover ley without nitrogen fertiliser was compared with an all-grass ley receiving 75 kg N/ha for each cut at silage stage. Also at this time, these two systems of grass management, much N *v.* no N, were compared on some of the reseeded grass and all the permanent grass.

5. All experiments included a test of farmyard manure to the root test crop, 30 t/ha once in six years at Rothamsted, 38 t/ha once in five years at Woburn. The effect of FYM is discussed for the Woburn results but not for those at Rothamsted where only three dressings were given.

6. At the start of the experiments the soils had different amounts of organic matter. There was 1·02% C on Series D, Stackyard Field at Woburn in 1938, farmed on a Norfolk four-course rotation since 1876; at Rothamsted in 1949, soil of Fosters Field had 1·65% C following a long rotation of arable crops, and the soil of Highfield, long in permanent grass contained 2·75% C.

7. All the arable rotations lost organic matter. At Woburn, the total loss was about 14% of the organic matter originally present and this continued steadily during 28 years. On Fosters Field, it was less than 10% and no carbon was lost during the last few years. On Highfield, where there was much organic matter at the start, about 25% was lost

during 15 years but the rate of loss decreased markedly in the last few years. Continuous arable cropping did not decrease the organic matter content of the three soils to the same amount, even after more than 20 years.

8. In all three experiments, after growing a three-year lucerne ley, the soil had only a little more organic matter than soil under an all-arable rotation.

9. Of the three-year leys the grazed ley increased soil organic matter most but only by about 10%. This was not enough to increase the amount of organic matter at Woburn to equal that on Fosters or that on Fosters to equal that on Highfield. At Woburn, giving 38 t FYM/ha every fifth year to the first test crop following the ley increased organic matter by 35% during 28 years. At Rothamsted a cut grass ley increased organic matter rather less than the grazed ley.

10. Organic matter increased most with reseeded and permanent grass (tested at Rothamsted only). More soil organic matter was conserved when the grass was grazed than where it was cut at silage stage. During the first 12 years while grazing lasted, soil organic matter increased by about 30% with reseeded grass on both Highfield and Fosters. During the following six years, when the reseeded grass was cut repeatedly at silage stage, soil organic matter decreased, and after six years there was only 15 to 20% more than at the start of the experiment.

11. Soil organic matter was maintained better by a long period (9 to 12 years) in grass followed by an equally long period in continued arable cropping rather than by alternating three years of ley with three years of arable cropping.

12. Additional organic matter was applied at Woburn as FYM once every five years. The effect of three to five dressings, each of 38 t/ha, was less where the soils were ploughed every year for arable crops than where grazed ley and lucerne remained unploughed for three years. The increases in organic carbon were 25 and 40% of the amounts applied in FYM for the all-arable and the ley systems respectively.

13. At Woburn the effects of having each of the four cropping systems (i) always on the same plot was compared with (ii) having the cropping systems follow one another on each plot, arable and ley systems alternating. During the twenty-eight years of the experiment alternating the treatment sequences conserved organic matter rather than accumulated it as with continuous grazed ley or decreased it as with continuous arable cropping.

Acknowledgements

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APPENDIX

Methods of sampling and analysis

Rothamsted Ley–Arable experiments. Soil samples were always taken with a 2 cm diameter semi-cylinder sampler. From 1956 to 1962 plots were sampled at the end of the third treatment or third test year. Since 1964 most samples were taken at the end of the third treatment year to determine the maximum effect of the leys.

Samples were taken from other blocks in 1956–57, in addition to those for organic carbon, to estimate amounts of readily-soluble P and K. d'Arifat and Warren (1965) discussed only the results from samples taken for organic carbon determinations. Subsequently it was observed that, after the first few years of the experiments, the amounts of organic matter changed little over periods of one or two years and that block differences, although not large, could not be ignored. The organic carbon contents of some of the soils sampled in 1956–57 were determined recently, together with those of soils sampled since 1964, to provide average results from as many blocks as possible.

At the start of the experiments ploughing was shallow, not more than 15 cm deep, especially on Highfield, During the experiments ploughing depth increased to about 23 cm as more powerful tractors were used. Initially soil sampling was done at two depths, 0 to 15 and 15 to 30 cm but since 1968 the 0 to 22·5 cm depth only was sampled. For comparisons throughout the experiment a weighted mean of the results for the 0 to 15 and 15 to 30 cm depths was used to get a value for the 0 to 22·5 cm depth. The validity of this was tested by comparing results from two sets of samples taken in 1967. A weighted mean for the 0 to 22·5 cm depth, calculated from the individual results of the 0 to 15 and 15 to 30 cm depths, was about 10% less than for the sample taken directly from the 0 to 22·5 cm for all four treatment sequences, arable, lucerne, grass–clover ley and ley-with-N. This effect was small but would explain the slight anomaly in the Fosters results discussed earlier.

When potatoes were grown as a test crop the plots were split to test farmyard manure (FYM). The dressing, 30 t/ha was applied once in six years; only three dressings, i.e. 90 t/ha, were applied during the period considered. On the basis of the results given in detail in the section on the Woburn Ley-Arable experiment, 90 t/ha could have increased the amount of soil carbon by between 0·05% C with continuous arable, and 0·09% C with grazed ley. From 1949–61 potatoes were also grown in the arable treatment rotation, seeds hay, potatoes, barley, and two of the four subplots in each plot received 30 t/ha of FYM. This test of FYM ceased when sugar beet replaced potatoes in this rotation. In practice, however, the subplots testing FYM were not sampled separately but equal numbers of soil cores were always taken from both subplots.

Most of the samples taken between 1956 and 1962 were analysed by the Walkley–Black method (1934) and the % C determined was multiplied by a factor of 1·3. Earlier samples, together with the extra 1956–57 samples and all those since 1963, were analysed by Bremner and Jenkinson's (1960) modification of Tinsley's method with slight further modification that reflux condensers were used to prevent evaporation of the solution. When the two methods were compared on these Rothamsted soils it was found that the results were closely related. Results by the Tinsley method were, on average, 95% of those by the Walkley–Black method where the % C as determined had been multiplied by the factor 1·3. Each Walkley–Black result was therefore converted to a 'Tinsley carbon' by multiplying by 0·95. In practice it was found that when a weighted mean for the 0 to 22·5 cm depth was multiplied by 0·95 to give a 'Tinsley carbon' the result was almost identical with that given by d'Arifat and Warren (1964) for the % C, measured by the Walkley–Black method, for the 0 to 30 cm depth.

Appendix Tables 1, 2 and 3 give, in detail, the results from the Rothamsted experiments.

Woburn Ley–Arable experiment. Soil samples taken from each block before the experiment started had been kept; they were analysed recently for organic carbon. Since 1956 soil samples were always taken with a 2 cm diameter semi-cylinder sampler. In 1956, 1957 and 1960 all plots were sampled; subsequently sampling was done at the end of the third treatment year. Sampling was always to the same depth, 0 to 25 cm, and the subplots with and without FYM were sampled separately. As with the Rothamsted results, it was observed that although the amount of organic matter changed little over one or two years it was necessary to average results from the same blocks. To do this, samples taken in 1956, 1957 and 1960 and which were one year away from the third treatment year were analysed and the results used as though the samples had been taken in the third treatment year. These soils were originally sampled to measure changes in the amounts of readily soluble P and K, the organic carbon content of all samples were determined only recently. All samples were analysed by the Bremner and Jenkinson (1960) modification of Tinsley's method as used for many of the Rothamsted soils. All results are given as % C (Tinsley method) in air dry soil 0 to 25 cm depth.

Appendix Tables 4 and 5 give, in detail, the results from the Woburn experiment.

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APPENDIX TABLE 1

Mean amount of carbon in the soils of the four cropping systems. Rothamsted Ley–Arable experiments, 1949–72

(% C in the 0–22·5 cm depth of soil, mean of four treatments* in each block)

Years after start of experiment	Block 1	2	3	4	5	6	7	8	9	10	11	12
					Highfield							
6	2·48	—	—	2·38	2·65	2·42	2·47	2·46	2·82	2·53	2·68	2·91
9	2·31	2·44	2·34	2·22	2·42	2·30	2·32	2·32	2·57	2·42	2·48	2·65
12	2·35	—	—	2·25	2·20	2·05	2·17	2·07	2·33	2·37	2·38	2·37
15–18	2·06	—	—	1·93	2·16	2·09	2·19	1·80	2·09	2·27	2·29	2·23
21–22	—	—	—	—	2·10	2·03	2·08	2·00	2·06	2·10	2·21	2·22
					Fosters Field							
6	1·59	—	1·65	—	1·65	1·54	1·54	1·52	1·57	1·63	1·53	1·53
9	1·46	1·52	1·55	1·57	1·59	1·60	1·47	1·47	1·42	1·52	1·56	1·48
12	1·51	—	1·54	—	1·43	1·39	1·39	1·39	1·35	1·52	1·38	1·49
15–18	1·52	—	1·56	—	1·53	1·43	1·43	1·58	1·52	1·54	1·38	1·51
21–22	—	—	—	—	1·56	1·52	1·51	1·58	1·54	1·60	1·50	1·53

* The four treatments were: all-arable, lucerne, cut grass/ley-with-N and grazed ley/ley-with-clover

APPENDIX TABLE 2

Amounts of organic carbon in the soils of the different cropping systems. Rothamsted Ley–Arable experiments, 1949–72
Blocks starting with treatment crops, Highfield 5, 8, 9, 12, Fosters Field 5, 7, 6, 11[1]

(% C in the 0–22·5 cm depth of soil (Tinsley method))

			Highfield							Fosters Field					
Year	Years after start of experiment	Cropping sequence[2]	Blocks	Arable (A)	Lucerne (Lu)	Cut grass/ Ley-with-N (Cg/Ln)	Grazed ley/Ley-with-clover (L/Lc)	Re-seeded grass (R)	Permanent grass (G)	Blocks	Arable (A)	Lucerne (Lu)	Cut grass/ Ley-with-N (Cg/Ln)	Grazed ley/Ley-with-clover (L/Lc)	Re-seeded grass (R)
1955	6	TrTs	5, 8	2·65	2·54	2·48	2·54	2·77	3·23	5, 7	1·54	1·60	1·64	1·60	1·72
1956			9, 12	2·69	2·70	2·72	2·77	3·07	3·25	6, 11	1·41	1·54	1·60	1·60	1·76
			mean	2·67	2·62	2·60	2·66	2·92	3·24		1·48	1·57	1·62	1·60	1·74
1958	9	TrTsTr	5, 8	2·11	2·45	2·39	2·54	3·14	3·49	5, 7	1·43	1·47	1·58	1·62	1·98
1959			9, 12	2·41	2·57	2·67	2·76	3·48	3·83	6, 11	1·39	1·52	1·67	1·75	2·05
			mean	2·26	2·51	2·53	2·65	3·31	3·66		1·41	1·50	1·62	1·68	2·02
1961	12	TrTsTrTs	5, 8	2·01	2·14	2·14	2·25	3·23	3·55	5, 7	1·35	1·33	1·48	1·48	2·12
1962			9, 12	2·26	2·28	2·40	2·45	3·79	3·95	6, 11	1·32	1·35	1·40	1·47	2·31
			mean	2·14	2·21	2·27	2·35	3·51	3·75		1·34	1·34	1·44	1·48	2·22
1964	15	TrTsTrTsTr	5, 8	1·95	2·12	1·88	1·98	2·64	3·23	5, 7	1·42	1·42	1·55	1·54	2·04
1965			9, 12	2·10	2·06	2·28	2·21	3·18	3·60	6, 11	1·30	1·38	1·40	1·56	1·98
			mean	2·02	2·09	2·08	2·10	2·91	3·42		1·36	1·40	1·48	1·55	2·01
1967	18	TrTsTrTsTrTs	Samples were not taken												
1968															
1971	21/22	TrTsTrTsTrTsA	5, 8	1·92	2·10	2·03	2·17	2·29[3]	2·74[5]	5, 7	1·52	1·48	1·57	1·56	1·78[3]
			9, 12	2·08	2·10	2·16	2·21	2·94[4]	3·02[6]	6, 11	1·40	1·50	1·56	1·58	2·01[4]
			mean	2·00	2·10	2·10	2·19	2·62	2·88		1·46	1·49	1·56	1·57	1·90

[1] Highfield blocks 2, 3, Fosters blocks 2, 4 are omitted because samples were not taken in 1954 and 1963
[2] Tr—3 years of treatment crops. Ts—3 years of arable test crops. A—continuous arable crops, mainly cereals
[3] Reseeded grass ploughed autumn 1964 continuous arable cropping since
[4] Reseeded grass ploughed autumn 1968 continuous arable cropping since
[5] Permanent grass ploughed autumn 1967 continuous arable cropping since
[6] Permanent grass ploughed autumn 1968 continuous arable cropping since

APPENDIX TABLE 3

Amounts of organic carbon in the soils of the different cropping systems. Rothamsted Ley–Arable experiments, 1949–72
Blocks starting with test crops, Highfield 6, 7, 10, 11, Fosters Field 8, 9, 10, 12[1]

(% C in the 0–22·5 cm depth of soil (Tinsley method))

			Highfield							Fosters Field					
Year	Years after start of experiment	Cropping sequence[2]	Blocks	Arable (A)	Lucerne (Lu)	Cut grass/ Ley-with-N (Cg/Ln)	Grazed ley/Ley-with-clover (L/Lc)	Re-seeded grass (R)	Permanent grass (G)	Blocks	Arable (A)	Lucerne (Lu)	Cut grass/ Ley-with-N (Cg/Ln)	Grazed ley/Ley-with-clover (L/Lc)	Re-seeded grass (R)
1955	6	TsTr	6, 7	2·40	2·42	2·39	2·58	2·90	3·05	8, 9	1·46	1·57	1·56	1·58	1·74
1956			10, 11	2·58	2·62	2·78	2·43	3·12	3·16	10, 12	1·54	1·48	1·67	1·63	1·79
			mean	2·49	2·52	2·58	2·50	3·01	3·10		1·50	1·52	1·62	1·60	1·76
1958	9	TsTrTs	6, 7	2·28	2·18	2·27	2·50	3·31	3·45	8, 9	1·38	1·42	1·45	1·50	1·98
1959			10, 11	2·50	2·38	2·49	2·43	3·40	3·68	10, 12	1·53	1·47	1·51	1·49	2·13
			mean	2·39	2·28	2·38	2·46	3·36	3·56		1·46	1·44	1·48	1·50	2·06
1961	12	TsTrTsTr	6, 7	1·93	2·11	2·09	2·28	3·32	3·61	8, 9	1·27	1·35	1·42	1·43	2·03
1962			10, 11	2·26	2·36	2·44	2·43	3·10	3·85	10, 12	1·39	1·47	1·58	1·57	1·93
			mean	2·10	2·24	2·26	2·36	3·21	3·73		1·33	1·41	1·50	1·50	1·98
1964	15	TsTrTsTrTs	Samples were not taken												
1965															
1967	18	TsTrTsTrTsTr	6, 7	2·02	2·07	2·14	2·34	3·15	3·27	8, 9	1·43	1·50	1·59	1·69	2·02
1968			10, 11	2·14	2·20	2·42	2·35	2·59[3]	3·46	10, 12	1·44	1·44	1·60	1·61	1·72[3]
			mean	2·08	2·14	2·28	2·34	3·08[6]	3·36		1·44	1·47	1·60	1·65	1·97[6]
1971	21/22	TsTrTsTrTsTrA	6, 7	1·88	2·07	2·06	2·22	2·52[4]	2·62[4]	8, 9	1·44	1·58	1·61	1·60	1·82[4]
			10, 11	2·04	2·06	2·30	2·22	2·40[3]	2·86[5]	10, 12	1·48	1·50	1·64	1·62	1·72[3]
			mean	1·96	2·06	2·18	2·22	2·46	2·74		1·46	1·54	1·62	1·61	1·77

[1] Highfield blocks 1, 4 and Fosters blocks 1, 3 are omitted because samples were not taken in 1963 and 1969
[2] Tr—3 years of treatment crops. Ts—3 years of arable test crops. A—continuous arable crops, mainly cereals
[3] Reseeded grass ploughed autumn 1962 continuous arable cropping since
[4] Reseeded and permanent grass ploughed autumn 1967 continuous arable cropping since
[5] Permanent grass ploughed autumn 1968 continuous arable cropping since
[6] Includes one estimated value

APPENDIX TABLE 4

Percentage organic carbon in the surface soils (0–25 cm) of the Woburn Ley–Arable experiment, 1938–69

(Plots where treatment sequences were continuous[1])

			Block											
			3		5		4		2		1		Mean	
Period	Years	Rotation	0	FYM	0	FYM	0	FYM	0	FYM	0	FYM	0	FYM
After 18 years	1955–59	Arable-roots	0·986	0·986	0·906	0·977	1·164	1·122	0·821	1·053	0·689	0·871	0·913	0·991
		Arable-hay	1·014	1·250	1·205	1·234	1·032	1·190	0·780	0·860	0·866	0·796	0·979	1·066
		Lucerne	0·970	1·028	1·049	1·238	1·312	1·318	0·819	0·922	0·837	1·203	0·997	1·142
		Grazed ley	1·144	1·398	1·076	1·184	1·310	1·290	1·052	1·221	0·904	0·978	1·097	1·214
After 23 years	1960–64	Arable-roots	0·897	0·982	0·927	1·000	1·200	1·098	0·798	0·989	0·673	0·776	0·899	0·969
		Arable-hay	0·934	1·138	1·168	1·294	0·972	1·144	0·810	0·912	0·839	0·859	0·945	1·069
		Lucerne	0·896	0·967	1·048	1·266	1·251	1·300	0·773	0·864	0·812	1·128	0·956	1·105
		Grazed ley	1·010	1·370	1·144	1·364	1·360	1·410	1·043	1·236	0·916	1·027	1·095	1·281
After 28 years	1965–69	Arable-roots	0·883	0·982	0·916	0·908	1·154	1·190	0·766	1·018	0·684	0·795	0·881	0·979
		Arable-hay	0·896	1·050	1·146	1·143	1·040	1·186	0·736	0·942	0·917	0·870	0·947	1·038
		Lucerne	0·841	0·988	0·954	1·200	1·250	1·270	0·830	0·899	0·892	1·289	0·953	1·129
		Grazed ley	1·136	1·419	1·096	1·264	1·299	1·368	1·100	1·348	1·008	1·206	1·128	1·321

[1] Example (a) Arable roots, test crops, arable roots, test crops, etc.
(b) Lucerne, test crops, lucerne, test crops, etc.

APPENDIX TABLE 5

Percentage organic carbon in the surface soils (0–25 cm) of the Woburn Ley–Arable experiment, 1938–69

(Plots where treatment sequences were alternated)

Plots starting 1938–42 with	Period	Sequence of treatments* since the start of the experiment	Block 3: 0	Block 3: FYM	Block 5: 0	Block 5: FYM	Block 4: 0	Block 4: FYM	Block 2: 0	Block 2: FYM	Block 1: 0	Block 1: FYM	Mean: 0	Mean: FYM
Arable-roots (Ar)	18 years	Ar 1 a 1	1·214	1·190	1·148	1·165	1·145	1·308	0·926	1·094	0·947	1·292	1·076	1·210
Arable-hay (Ah)	1955–59	Ah 1 a 1	1·012	1·357	1·138	1·208	1·037	1·015	0·858	0·924	0·712	0·861	0·951	1·073
Lucerne (Lu)		Lu a 1 a	0·956	1·104	0·928	1·076	1·056	1·222	0·936	0·972	0·986	1·051	0·972	1·085
Grazed ley (L)		L a 1 a	0·899	1·064	0·986	1·008	1·098	1·229	0·892	1·070	0·870	1·091	0·949	1·092
Arable-roots (Ar)	23 years	Ar 1 a 1 a	1·035	1·105	1·130	1·210	1·094	1·196	0·849	1·096	0·927	1·211	1·007	1·164
Arable-hay (Ah)	1960–64	Ah 1 a 1 a	0·946	1·158	1·160	1·337	0·994	0·998	0·872	0·908	0·760	0·875	0·946	1·055
Lucerne (Lu)		Lu a 1 a 1	0·890	0·920	0·960	1·173	1·011	1·168	0·792	0·921	1·022	1·021	0·935	1·041
Grazed ley (L)		L a 1 a 1	0·896	1·041	1·026	1·174	1·246	1·364	0·974	1·124	0·950	1·174	1·018	1·175
Arable-roots (Ar)	28 years	Ar 1 a 1 a 1	1·009	1·121	1·234	1·109	1·080	1·256	0·963	1·172	0·926	1·303	1·042	1·192
Arable-hay (Ah)	1965–69	Ah 1 a 1 a 1	0·982	1·254	1·044	1·166	1·133	1·138	0·844	0·911	0·857	1·028	0·972	1·099
Lucerne (Lu)		Lu a 1 a 1 a	0·863	0·948	0·912	1·014	1·042	1·251	0·806	0·946	1·009	0·941	0·926	1·020
Grazed ley (L)		L a 1 a 1 a	0·848	1·060	0·947	1·048	1·146	1·386	0·852	1·164	0·988	1·296	0·956	1·191

* a Either arable-with-hay or arable-with-roots
1 Either lucerne or grazed ley