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Experiments Made on Stackyard Field, Woburn, 1876-1974 I. History of the Field, Details of the Cropping and Manuring and the Yields in the Continuous Wheat and Barley Experiments

A. E. Johnston

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Experiments made on Stackyard Field, Woburn, 1876-1974

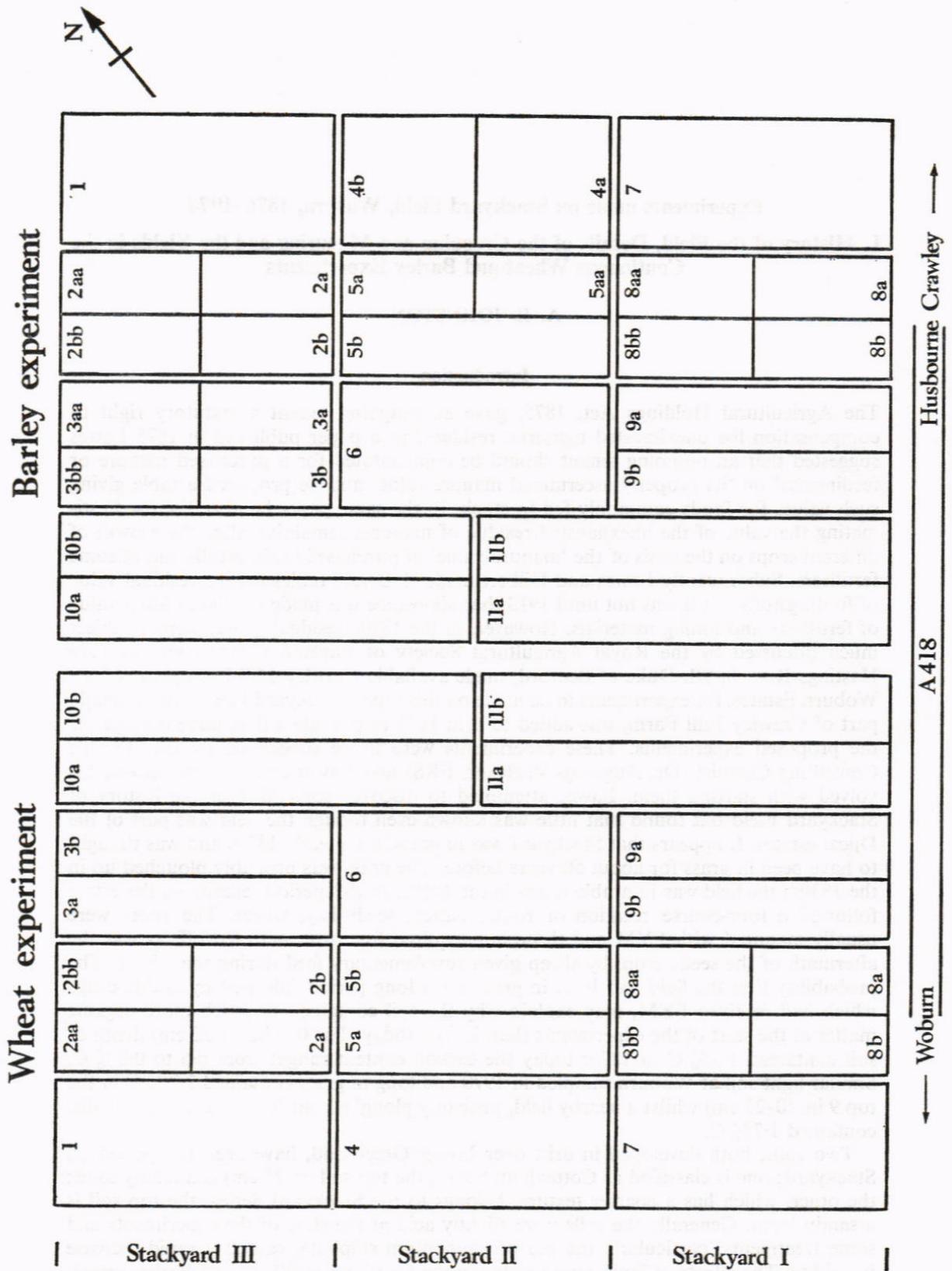
I. History of the Field, Details of the Cropping and Manuring and the Yields in the Continuous Wheat and Barley Experiments

A. E. JOHNSTON

Introduction

The Agricultural Holdings Act, 1875, gave an outgoing tenant a statutory right to compensation for unexhausted manurial residues. In a paper published in 1875 Lawes suggested that an outgoing tenant should be compensated for a purchased manure or feedingstuff on 'its properly ascertained manure-value' and he produced a table giving such values for foods commonly fed to stock. In the same paper he also discussed estimating the value of the unexhausted residue of manures remaining after the growth of different crops on the basis of the 'manure-value' of purchased feedingstuffs and of some fertilisers. Subsequently Lawes and Gilbert made elaborate tables for the residual value of feedingstuffs but it was not until 1913 that allowance was made for the residual value of fertilisers and liming materials. However, in the 1870s residual values were a subject much discussed by the Royal Agricultural Society of England (RASE) and in 1876 Hastings Russell, 9th Duke of Bedford, made available Crawley Mill Farm, part of the Woburn Estates, for experiments to be made on this topic. Stackyard Field, not originally part of Crawley Mill Farm, was added to it in 1876 to provide a field large enough for the proposed experiments. These experiments were to be supervised by the RASE's Consulting Chemist (Dr. Augustus Voelcker, FRS) and Lawes and Gilbert became involved with starting them. Lawes attempted to discover something of the history of Stackyard Field but found that little was known even though the field was part of the Ducal estates. It appears that Stackyard was in grass in the early 1820s and was thought to have been in grass for about 50 years before. The grass was probably ploughed up in the 1830s; the field was in arable crops in the 1860s. In this period tenants on the estate followed a four-course rotation of roots, barley, seeds-hay, wheat. The roots were usually manured with FYM and those not required for cattle were fed off, as was the aftermath of the seeds crop, by sheep given supplementary feed during the winter. The probability that the field had been in grass for a long period followed by arable crops which had received FYM, may explain why the soil contained so much more organic matter at the start of the experiments than it does today. The 0-9 in. (0-23 cm) depth of soil contained 1.5% C in 1876; today the carbon content ranges from 0.6 to 0.9% C. Similar light soil at Woburn sampled in 1970 and long in grass contained 2.7% C in the top 9 in. (0-23 cm) whilst a nearby field, probably ploughed out from grass in the 1940s, contained 1.7% C.

Two soils, both developed in drift over Lower Greensand, have been recognised on Stackyard; one is classified as Cottenham Series, the top soil (0-23 cm) is a loamy sand; the other, which has a coarser texture, belongs to the Stackyard Series, the top soil is a sandy loam. Generally the soils were slightly acid at the start of the experiments and some treatments, particularly the use of ammonium sulphate, caused a rapid increase in acidity. The effects of liming were tested in the Continuous Wheat and Barley experiments and an occasional dressing of lime was given to the rest of the field but the pH in water was not increased above about 6.5 before the early 1960s. Until the late 1950s experiments on Stackyard were occasionally affected by changing soil pH as well as by



Notation used since 1966 -

FIG. 1. Plan of the Continuous Wheat and Barley experiments showing the arrangement of the plots. For treatments see p. 32.

EXPERIMENTS ON STACKYARD FIELD. I

difficulties in controlling weeds and getting good establishment of crops from small seeds.

In 1876 the field was divided into five sections which have remained almost unchanged. Four of the sections, each about 4 acres (1.6 ha), were for the rotation experiment which tested the residual manurial value of feedingstuffs whilst on the fifth section, about 5.5 acres (2.2 ha), the Continuous Wheat and Barley experiments were made. The results of these experiments and others made at Woburn from 1876 to the early 1930s were discussed in detail by Russell and Voelcker (1936).

The Continuous Wheat and Barley experiments, 1877-1966

The Classical experiments at Woburn on the continuous growing of cereals started with sowing winter wheat in autumn 1876 and barley in spring 1877. Whilst cereals were grown each year before 1926 the experiments had to be fallowed in many years since and so cereals were not grown as continuously as in the Classical experiments on Broadbalk and Hoosfield at Rothamsted. The plots were laid out as for the barley experiment on Hoosfield at Rothamsted; strip treatments with and without PKNaMg were crossed at right angles by strips with and without N. Separate plots also tested FYM. Fig. 1 shows a plan of the experiments with the plot numbers, details of the treatments are on p. 32. Initially the amounts of fertiliser tested each year were the same as those used on cereals at Rothamsted; the fertilisers available at that time probably supplied about 41 and 82 lb (46 and 92 kg) N, 30 lb (34 kg) P, 80 lb (90 kg) K, 14 lb (16 kg) Na and 10 lb (11 kg) Mg per acre (per ha). FYM was tested at two amounts which averaged 3.5 and 7.0 tons/acre (8.8 and 17.6 t/ha) over the whole period of the experiment. Plots receiving the larger amount of N were halved in 1882; each half was fertilised only in alternate years to measure the effects of N residues. Major manurial changes were made for crops harvested in 1907; both amounts of N were halved, superphosphate was given at 3 cwt/acre (25 lb P/acre, 28 kg P/ha), potassium at only 0.5 cwt potassium sulphate/acre (22 lb K/acre, 25 kg K/ha), sodium and magnesium were omitted and the larger amount of FYM was tested on one half plot only. The remaining FYM plots tested NP, NK and rape cake. Table 1 gives the manurial history and Table 2 details of the manures used.

TABLE 1

MANURIAL HISTORY OF THE CONTINUOUS WHEAT AND BARLEY EXPERIMENTS

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TABLE 2

DETAILS OF MANURES 1877-1926, 1931-32

Pages 33-34

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TABLE 1

MANURIAL HISTORY OF THE CONTINUOUS WHEAT AND BARLEY EXPERIMENTS

In both experiments plots with the same plot number had the same treatment
Manurial treatment 1877-1926 manures applied annually, except as given below

Plot	Treatment
No nitrogen group	
1	Unmanured.
7	Unmanured.
4	P K Na Mg.
Ammonium-N group	
2	N ₂ , N ₁ since 1907.
5	N ₂ PKNaMg, N ₁ since 1907.
8	N ₄ PKNaMg. From 1882 the plot was split; subplots 8a and 8b had N applied in alternate years only; plot 8a, dressing omitted 1882 applied in 1883, plot 8b, dressing applied 1882 omitted in 1883; N ₂ since 1907.
Nitrate-N group	
3	N ₂ . From 1907 the plot was divided, plot 3a received N ₂ , plot 3b N ₁ .
6	N ₂ PKNaMg, N ₁ since 1907.
9	N ₄ PKNaMg. From 1882 the plot was split; subplots 9a and 9b had N applied in alternate years only; plot 9a dressing omitted 1882 applied in 1883, plot 9b dressing applied 1882 omitted in 1883; N ₂ since 1907.
10a	N ₁ P 1907-26 only, see below for earlier years.
11a	N ₁ K 1907-26 only, see below for earlier years.
Organic manure group	
10a	FYM ₁ 1877-81, 1882-1906 unmanured except 1889 rape cake to supply 41 lb N/acre (46 kg N/ha).
10b	FYM ₁ 1877-87, 1888 unmanured. 1889-1906 rape cake, weights adjusted to supply the following amounts of N per acre: 1889, 41 lb N; 1890-1906, 82 lb N; 1907-26, 20.5 lb N (these N dressings are 46, 92 and 23 kg/ha respectively).
11a	FYM ₂ 1877-81; 1882-1906, unmanured.
11b	FYM ₂ 1887-1926.

EXPERIMENTS ON STACKYARD FIELD. I

TABLE 2
DETAILS OF MANURES 1877-1926, 1931-32

Amounts per acre (in brackets, per ha)

NITROGEN

1877-1906 N₂, N₄: 41, 82 lb N (46, 92 kg N) either as mixed ammonium salts (equal quantities of ammonium sulphate and ammonium chloride) or sodium nitrate. 1907-26 N₁, N₂: 20.5, 41 lb N (23, 46 kg N) either as ammonium sulphate or sodium nitrate.

From 1877-81 the N₄ dressing was divided into two equal amounts and applied in spring on two occasions. From 1882 the N₄ dressing (still given on two occasions in spring) was applied only in alternate years, plots 8 and 9 being halved to show each year the direct and residual N effects when PKNaMg were applied each year.

PHOSPHORUS

1877-1906: Superphosphate to supply 65 lb P₂O₅, about 30 lb P (73 kg P₂O₅, 34 kg P). In the first few years this superphosphate was made from 200 lb bone ash and 150 lb sulphuric acid (as at Rothamsted).

1907-26: 3 cwt (377 kg) commercial superphosphate containing about 14% P₂O₅; this would supply 47 lb P₂O₅, about 20 lb P (53 kg P₂O₅, 22 kg P).

POTASSIUM

1877-1906: Potassium sulphate to supply 98 lb (110 kg) K₂O (about 80 lb or 90 kg K).

1907-26: Potassium sulphate to supply 27 lb (30 kg) K₂O except on plot 11a which got 54 lb (60 kg) K₂O (about 44 lb or 49 kg K).

SODIUM AND MAGNESIUM

Applied only from 1877 to 1906; both given as sulphates to supply 14 lb (16 kg) Na and 10 lb (11 kg) Mg.

FARMYARD MANURE

There is now no record of the actual amounts of FYM applied but every effort has been made to estimate the amounts used because of their importance in relation to the accumulation and loss of organic matter and organic phosphorus.

During the first 20 years of the experiments the observations made on the crops and the results obtained were published each year by the Consulting Chemist in the *Journal of the Royal Agricultural Society (JRAS)*. From these accounts the original intention was to use sufficient FYM each year to apply total N equal to 100 and 200 lb NH₃/acre (112 and 224 kg NH₃/ha) 82 and 165 lb N/acre (92 and 185 kg N/ha) at the single and double rate tested. The actual weights of FYM used were to be calculated from the estimated composition of FYM made by cattle in covered boxes at the Farm. The estimated composition was based on a knowledge of the weights and average composition of the cake, roots and straw fed to the cattle, allowance being made for nutrient retention by the animal according to tables produced by Lawes and Gilbert. The FYM was made during the early winter, carted out and clamped under cover. In the early years of the experiment, when it was applied as a top dressing it was used almost immediately. Later, when the FYM was ploughed in it was stored during the summer for application the following autumn. Times of application were:

Winter wheat	1877-1906 as a top-dressing in February 1907-26 ploughed in in October.
Barley	1877-88 ploughed in in February before spring sowing 1889-1906 as a top-dressing in March or April 1907-26 ploughed in in March.

During the first 14 years the tables published annually in *JRAS* indicate that the double rate of FYM was about 8 tons/acre (20 t/ha) until 1888 and then about 7 tons/acre (17.6 t/ha) in 1889 and 1890. No weights have been found for the remaining years to 1906 but the account of the first 20 years of the experiments in the *JRAS* for 1897 suggests that the double rate of FYM was about 7 tons/acre (17.6 t/ha). Using what published results there are and assuming that the weight used was 7 tons/acre (17.6 t/ha) from 1890-1906 the average annual dressing for the first 30 years was 7.86 tons/acre (19.7 t/ha).

J. A. Voelcker (*JRAS*, 1907, 68, p. 242) giving reasons for the changes in manuring introduced in 1907 suggested that much less N was applied in the first 30 years than was thought at the time. Presumably there was much less than 165 lb N (185 kg N) in 7.86 tons (19.7 t) FYM. Work at Woburn in 1899-1901 had shown considerable loss of N in making FYM, some of the loss occurred in the boxes as the manure accumulated and some during storage in clamps even though these were protected from the rain. A summary of these results by Russell and Voelcker (1936) suggests that about 35% of the total N was lost. It is almost certain that this loss was not allowed for during the first 30 years of the experiments. Using the average loss (33.8%) from the experimental results suggests that the double rate of FYM would have supplied 109 lb N/acre (122 kg N/ha). Russell and Voelcker (1936) in their account of the first 50 years of the experiment do apparently make a correction for this loss. In their Table 119 instead of giving the single and double rate of FYM as supplying 82 and 165 lb N/acre (92 and 185 kg N/ha) respectively during the first 30 years they decreased the amounts to 53 and 105 lb N/acre (59 and 118 kg N/ha).

From 1907 to 1926 FYM was tested only at the larger amount. Each year the FYM was analysed and

B

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TABLE 2—continued

the amount applied was adjusted to supply 100 lb NH₃/acre (112 kg NH₃/ha) (82 lb N/acre, 92 kg N/ha). In 1907 and 1908 the actual weights of FYM used are given as about 6 and 5 tons/acre (15.0 and 12.5 t/ha). No further weights are given in the published results but these approximate weights check with that given above if the composition of the FYM changed little; 109 lb N in 7.86 tons FYM corresponds to 82 lb N in 5.91 tons FYM or 122 kg N in 19.7 t FYM corresponds to 92 kg N in 14.8 t FYM.

From this evidence, if the average dressing of the double rate of FYM in the first 30 years was 7.86 tons/acre (19.7 t/ha) and in the last 20 years was 5.91 tons/acre (14.8 t/ha) then for the whole experiment the single and double dressings of FYM averaged 3.5 and 7.0 tons/acre each year, or 8.8 and 17.6 t/ha each year.

More recent results provide some confirmation for this estimate. Analyses of some 50 FYM samples applied to the Market Garden experiment at Woburn between 1942 and 1967 showed that they had a C/N ratio of 13/1 and a ton of fresh FYM contained 346 lb organic matter, so a tonne of fresh FYM contained 154 kg organic matter (Johnston & Wedderburn, 1975). If this C/N ratio applied to the FYM samples used from 1877-1926 then there was 122 kg N and 1586 kg carbon in dressings of about 17.6 t/ha.

N AND C APPLIED IN FYM. If the dressings used contained 109 lb N/acre (122 kg N/ha) in the first 30 years and 82 lb N/acre (92 kg N/ha) in the last 20 years then the total N applied was 4910 lb (5500 kg). (Crowther (1936) used the Russell and Voelcker result of 105 lb N/acre (118 kg N/ha) each year for the first 30 years.) An estimate of the carbon applied can be obtained using the results given above. If the FYM had a C/N ratio of 13/1 then the carbon added was 28.5 tons/acre (71.5 t/ha). If the FYM contained 346 lb organic matter/ton of fresh material then the carbon added was 31.8 tons/acre, or if the FYM contained 154 kg organic matter/tonne of fresh material then the carbon added was 78.5 t/ha.

P AND K IN FYM. The P and K content of FYM at Rothamsted (Warren & Johnston, 1962) for this period was checked where possible with that at Woburn in the Rotation experiments. In the first 30 years the double dressing of FYM probably contained 17 lb (19 kg) P and 50 lb (56 kg) K whilst during the last 20 years it contained 15 lb (16.8 kg) P and 40 lb (44.8 kg) K.

RAPE CAKE

Amounts were adjusted to supply known amounts of total N. Average analyses for rape cake during the period of the experiment show that there was 100 lb N in 2000 lb rape cake which also contained 20 lb P and 20 lb K (100 kg N, 20 kg P and 20 kg K in 2000 kg rape cake).

NPK TREATMENTS 1931-32

In these two years some plots on the Barley experiment were manured. Plots 8 and 9 received a total of 82 lb (92 kg) N, 50 lb (56 kg) P, 132 lb (148 kg) K; plot 10a received 61 lb (68 kg) N, 50 lb (56 kg) P; plot 11a received 61 lb (68 kg) N, 132 lb (148 kg) K. All the N was given as sodium nitrate.

TOTAL AMOUNTS OF P AND K APPLIED DURING THE EXPERIMENT

Estimates of the amounts of P and K added during the experiment can be calculated from the details given in the previous sections. These estimates, which correct those given by Johnston and Warren (1970), are:

Estimated amounts of P and K applied to each plot of the Continuous Wheat and Barley experiments, Woburn, 1877-1965^a

Plot	kg element/ha			
	Barley experiment		Wheat experiment	
	P	K	P	K
1 2 3 7	0	0	0	0
4 5 6	1457	3184	1457	3184
8 9	1513	3332	1457	3184
10a	560	146	504	146
10b	504	706	504	706
11a	95	1415	95	1267
11b	908	2578	908	2578

(a) P and K was applied to parts of plots 7, 8, 9, 11 of both experiments in 1960-62. For details see Johnston and Warren (1970).

LIMING

Split-plot dressings of chalk were tested between 1898 and 1924. The effects on yield are shown in Tables 3 and 4, the effects on soil reaction are discussed in Part II. During 1954-59 the surface soils were brought to pH 6 in water by applying different amounts of ground chalk to each plot. Details are given in Part II.

EXPERIMENTS ON STACKYARD FIELD. I

At the start of the experiment the soil was slightly acid and ammonium sulphate used to supply N increased the acidity considerably. Some tests of liming were made, details are in Part II, p. 47. Table 3 shows the yields of wheat and Table 4 those of barley in each ten-year period during 1877-1926. These mean yields have been calculated from the annual yields given by Russell and Voelcker (1936). It is assumed that their yields of grain and straw are as threshed after stooking and stacking, i.e. at about 85% dry matter. Though none of the yields were large by current standards those for the first ten-year period did show large responses to N, smaller ones to P plus K fertiliser. The effect of fresh and residual N on yield is best seen by comparing yields on plots 9a and 9b where yields were least affected by acidity. The effect of the chalk dressing on yield is best seen by comparing yields on plots 8a and 8aa and 8b and 8bb. In all other comparisons where chalk dressings were given yields were increased except on plot 3 of the Barley experiment where chalk was not tested until 1921 and where N was given as sodium nitrate without P and K. The large decrease in yield in the period 1907-16 compared to the earlier periods on plots given N and not badly affected by acidity, especially plot 9, must, in part at least, be due to the decreased N dressings given after 1907. Because of decreasing yields and increasing weediness of the plots, the Classical experiments were stopped in 1926 and no more FYM and P and K were applied, except that in 1931-32 some of the Barley experiment plots received small dressings of N, P and K fertilisers, for details see p. 34.

From 1927 to 1940 the plots continued to grow winter wheat or spring barley, testing, in two cycles each of seven years, the effects of two years fallow, 1927-28 and 1934-35, on the succeeding five unmanured cereal crops (for exceptions on the Barley experiment see p. 34). In 1941 and 1942, 47 lb N/acre (53 kg N/ha) as ammonium sulphate, were given as a basal dressing to all plots, except plots 2, 5 and 8 which were not cropped in either experiment. Tables 3 and 4 show the mean yields of both crops for the two five-year cropping periods, 1929-33 and 1936-40, when no N was given and average yields for 1941-42 when 53 kg N/ha was given. There was considerable variation in yield from year to year on individual plots and on some plots yields were very small. When the average yield of all plots for each year are examined there is a slight indication of a diminishing benefit from the two years of fallow:

Average yield, t/ha, of all plots for each year
(the plots were fallowed in 1927-28 and again in 1934-35)

Year after fallow	Wheat experiment				Barley experiment			
	grain		straw		grain		straw	
	1929- 1933	1936- 1940	1929- 1933	1936- 1940	1929- 1933	1936- 1940	1929- 1933	1936- 1940
1	0.65	0.76	1.01	1.26	1.24	1.12	1.49	1.95
2	0.14	0.70	0.49	1.43	0.67	0.14	0.72	0.39
3	0.45	0.76	1.14	1.04	0.74	0.76	1.81	0.66
4	0.44	0.42	1.35	0.96	0.28	0.47	0.91	1.20
5	0.15	0.36	0.58	0.68	0.05	0.04	1.03	0.47
Mean	0.37	0.60	0.92	1.07	0.60	0.50	1.19	0.93

It is interesting to look at the yields for the second year after fallow in both periods; 1930 was a very poor year for wheat, a better year for barley; in the second period the reverse was true, 1937 was a very poor year for barley, a better year for wheat. H. H. Mann (1943) discussed the effects of fallowing on yield in these two periods in relation to the yields between 1877 and 1926.

Tables 3 and 4 show there was little benefit from the 53 kg N/ha given in 1941 and 1942.

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TABLE 3
Yields of wheat grain and straw in the Continuous Wheat experiment, Woburn, 1877-1942

Plot	Manurial treatment* to whole plot 1877-1926		Sub-plot	Total chalk applied ^b 1898-1921 t/ha	Grain										Straw									
	Period	Treatment			1877-1886	1887-1896	1907-1916	1917-1926	1929-1933	1936-1940	1941-1942	1877-1886	1887-1896	1907-1916	1917-1926	1929-1933	1936-1940	1941-1942						
1	1877-1926	Unmanured	—	0	1.08	0.83	0.61	0.66	0.46	0.30	0.70	0.24	—	2.22	1.55	1.12	1.08	0.85	1.01	1.33	0.76			
2	1877-1906 1907-26	N ^a N ^a	2a	0	1.63	1.57	0.63	0.04	0.04	0.06	0.06	0	0.04	—	—	—	0.23	0.18	0.32	0.18	0			
			2aa	2.5	—	—	0.76	0.54	0.28	0.62	0.06	—	—	—	—	—	—	1.24	1.01	0.47	0.82	0.14		
			2b	5.0	—	—	1.12	0.54	0.28	0.62	0.06	—	—	—	—	—	—	1.76 ^b	1.55	1.00	0.70	1.05		
3a	1877-1926	N ^a ,d	2bb	10.0	—	—	0.94	0.60	0.23	0.64	0.32	—	—	—	—	—	1.62	1.07	0.66	1.02	0.72			
			3a	0	1.50	1.45	1.19	1.25	1.02	0.37	0.68	0.69	—	—	—	—	—	2.30	2.34	1.96	0.81	1.12		
3b ^k	1907-26	N ^a ,* N ^a ,*	—	0	—	—	—	1.07	0.89	0.30	0.55	0.54	—	—	—	—	1.88	1.60	0.64	0.89	1.01			
4	1877-1926	PKNaMg	—	0	1.13	0.83	0.59	0.61	0.56	0.49	0.92	0.92	—	—	—	—	1.09	1.08	1.47	1.73	2.20			
5	1877-1926 1907-26	N ^a ,PKNaMg N ^a ,PKNaMg	5a	0	2.04	1.94	1.68	1.11	0.64	0.46	0.60	0.19	—	—	—	—	—	1.70	1.25	1.19	1.21	0.58		
			5b	5.0	—	—	—	1.51	0.92	0.40	0.74	0.66	—	—	—	—	—	2.15	1.64	1.04	1.29	1.22		
7	1877-1926	N ^a ,PKNaMg N ^a ,PKNaMg	—	0	2.12	1.94	1.67	1.22	1.08	0.49	0.75	1.20	—	—	—	—	—	2.84	2.16	1.86	1.10	1.34		
			7a ^e	0	1.11	0.93	0.78	0.73	0.51	0.26	0.73	0.57	—	—	—	—	—	1.24	1.11	0.86	0.80	1.31		
			7aa	0	2.54	2.35	1.67	0.36	0.26	0.12	0.13	0	—	—	—	—	—	—	0.72	0.58	0.47	0.25	0	
			7b	2.5	—	—	1.25	0.66	0.39	0.62	0.08	—	—	—	—	—	—	—	1.97	1.33	0.91	1.05	0.33	
8	1877-1926	N ^a ,PKNaMg N ^a ,PKNaMg	8a ^e	0	1.35 ^g	1.64	1.12	0.31	0.21	0.16	0.13	0.03	—	—	—	—	—	2.25 ^g	2.78	1.79	0.58	0.37		
			8b ^e	2.5	—	—	—	0.95	0.58	0.42	0.66	0.25	—	—	—	—	—	—	1.47	0.97	0.94	1.08	0.77	
10a	1877-1906 1907-26	N ^a ,PKNaMg N ^a ,PKNaMg	9a ^e	0	2.42	1.93	2.07	1.28	1.03	0.48	0.65	1.05	—	—	—	—	—	4.00	3.70	2.42	2.02	1.18		
			9b ^e	0	1.12 ^h	1.06	0.84	0.73	0.58	0.52	0.72	0.81	—	—	—	—	—	2.16 ^h	1.80	1.45	1.23	1.04		
10b	1907-26	N ^a ,*p ⁱ Rape cake ^l	—	0	1.24 ^g	1.08	0.90	1.22	0.93	0.38	0.54	0.43	—	—	—	—	—	1.84	1.39	2.01	1.75	0.86		
			10b	0	1.37	1.72	1.88	1.34	0.85	0.29	0.58	0.42	—	—	—	—	—	3.01	3.21	2.07	1.47	0.67		
11a	1907-26	N ^a ,*K ¹	—	0	1.28 ^g	1.19	1.01	1.09	0.90	0.56	0.75	1.13	—	—	—	—	2.51 ^g	1.95	1.55	1.92	1.28			
11b	1877-1926	FYM	—	0	1.76	1.83	1.69	1.38	1.20	0.68	0.88	1.34	—	—	—	—	3.46 ^g	3.21	3.08	2.68	2.39			

(a) For full details see p. 32.
 (b) For full details see p. 47.
 (c) In the earlier years percentage dry matter was not determined but weights were recorded after stacking when grain and straw were probably at about 85% dry matter.
 (d) N—nitrogen applied as ammonium sulphate; N*—nitrogen applied as sodium nitrate.
 (e) From 1882 the a and b halves of the plot tested the direct and residual effect of the N dressing. The a half had the dressing omitted in 1882, applied in 1883, omitted in 1884, etc. The b half had the dressing applied in 1882, omitted in 1883, applied in 1884, etc. In recording the yields, the yield in the year of application is always attributed to the a half, the yield in the residual year is always attributed to the b half.
 (f) A basal dressing of 53 kg N/ha was given each year in 1941 and 1942.
 (g) Five years only, 1882-86.
 (h) Nine years only, 1898-1906.
 (i) Crops grown without fertiliser in 1929-33 and 1936-40 after two years fallow in 1927-28 and again in 1934-35.
 (k) Plot 3 was halved in 1907; 3a continued to receive N^a, plot 3b got N^a from 1907-26.
 (l) For details of treatments before 1907 see p. 32.

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TABLE 4
Yields of barley grain and straw in the Continuous Barley experiment, Woburn, 1877-1942

Plot	Manurial treatments ^a to whole plot 1877-1926		Sub-plot	Total chalk applied ^b 1898-1921 t/ha	Grain and straw, t/ha, at 85% dry matter														
	Period	Treatment			Grain				Straw										
	1877-1906	1907-1926			1877-1886	1887-1896	1907-1916	1917-1926	1929-1933	1936-1940	1941-1942	1877-1886	1887-1896	1907-1916	1917-1926	1929-1933	1936-1940	1941-1942	
1	1877-1906	Unmanured	2a	0	1.56	0.98	0.71	0.60	0.49	0.50	0.52	1.97	1.24	0.86	0.87	0.91	0.96	0.77	
2	1877-1906	N ₁ ^d	2aa	3-75	2.30	1.62	0.24	0.06	0.09	0.04	0.01	2.90	1.84	0.44	0.16	0.09	0.01	0	
			2b	10-0	—	—	0.42	0.32	0.45	0.54	0.24	—	—	0.80	0.70	0.91	1.20	0.77	
			2bb	10-0	—	—	1.30 ^h	0.87	0.51	0.54	0.43	0.45	—	—	1.42 ^h	1.30	0.94	0.99	0.88
3a	1877-1906	N ₃ ^d	3aa	5	2.35	1.77	1.43	0.93	0.67	0.69	0.61	3.15	2.25	1.75	1.62	1.15	1.24	0.98	
			3b	0	—	—	—	0.84	0.50	0.58	0.57	—	—	—	—	1.03 ⁱ	0.87	0.84	
			3bb	5	—	—	—	—	0.45 ⁱ	0.42	0.36	0.15	—	—	—	0.90 ⁱ	0.90	0.67	0.42
4	1877-1906	PKNaMg	4a	0	1.35	1.26	1.00	0.76	0.59	0.41	0.62	1.64	1.34	1.08	1.16	0.90	1.05	0.80	
			4b	2.5	—	—	—	0.67	0.53	0.51	0.40	—	—	—	1.04	0.94	0.86	1.14	
5	1877-1906	N ₁ PKNaMg	5a	0	2.57	2.10	0.44	0.19	0.30	0.09	0.02	3.28	2.37	0.66	0.43	0.53	0.38	0.02	0
			5aa	5	—	—	—	1.21	0.92	0.51	0.26	0.18	—	—	1.80	1.34	0.91	0.61	0.43
			5b	10	—	—	—	2.12 ^h	1.25	0.78	0.63	0.51	0.65	—	—	2.41 ^h	1.12	1.22	0.94
6	1877-1906	N ₁ *PKNaMg	6a	0	2.73	2.42	2.14	1.19	0.97	0.72	0.68	1.13	3.78	3.09	2.66	1.81	1.37	1.34	1.02
			6b	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	1877-1906	Unmanured	7a	0	1.33	1.03	0.82	0.51	0.42	0.47	0.41	0.36	1.71	1.20	0.89	0.81	0.72	0.90	0.85
			7b	0	3.05	2.32	0.92	0.22	0.11	0.02	0.03	0	4.20	3.04	1.15	0.32	0.16	0.04	0.03
			7c	10	2.24 ^g	1.66	0.80	0.10	0.06	0.05	0.03	0	—	—	2.78 ^g	1.96	1.38	1.64	0.99
8	1877-1906	N ₁ PKNaMg	8a	0	—	—	—	1.77 ^h	0.92	0.64	1.08	0.69	2.65 ^g	1.92	0.94	0.12	0.04	0.03	0
			8b	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			8bb	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9	1877-1906	N ₁ *PKNaMg	9a	0	3.13	2.59	2.64	1.52	1.16	1.11	0.76	4.82	3.79	3.38	2.49	1.72	2.02	1.24	
			9b	0	2.08 ^g	1.75	1.45	0.99	0.78	1.13	0.74	1.20	2.29 ^g	2.01	1.61	1.35	1.19	2.19	1.22
10a	1877-1906	N ₁ *P ⁱ		0	1.97 ^g	1.34	1.03	1.10	0.85	0.65	0.40	2.30 ^g	1.62	1.19	1.72	1.28	1.26	0.82	
10b	1877-1906	Rape cake ¹		0	1.80	1.92	2.06	1.06	0.51	0.17	0.29	2.23	2.34	2.53	1.49	0.92	0.54	0.71	
11a	1877-1906	N ₁ *K ¹		0	2.25 ^g	1.80	1.35	1.40	1.04	0.81	0.60	2.65 ^g	2.14	1.55	2.17	1.50	1.73	1.02	
11b	1877-1906	FYM		0	2.39	2.30	2.27	1.87	1.54	0.99	0.81	2.89	2.72	2.72	2.57	2.23	1.94	1.56	

(a) For full details see p. 32
 (b) For full details see p. 47
 (c) In the earlier years percentage dry matter was not determined but weights were recorded after stacking when grain and straw were probably at about 85% dry matter
 (d) N—nitrogen applied as ammonium sulphate; N*—nitrogen applied as sodium nitrate
 (e) From 1882 the a and b halves of the plot tested the direct and residual effect of the N dressing. The a half had the dressing omitted in 1882, applied in 1883, omitted in 1884, etc. The b half had the dressing applied in 1882, omitted in 1883, applied in 1884, etc. In recording the yields, the yield in the year of application is always attributed to the a half, the yield in the residual year is always attributed to the b half
 (f) A basal dressing of 53 kg N/ha was given each year in 1941 and 1942
 (g) Five years only, 1882-86
 (h) Nine years, 1898-1906
 (i) Six years only, 1921-26
 (j) Crops grown without fertiliser in 1929-33 and 1936-40 after two years fallow in 1927-28 and again in 1934-35
 (k) Plot 3 was halved in 1907; 3a continued to receive N₁, plot 3b got N₁ from 1907-26
 (l) For details of treatments before 1907 see p. 32

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From 1943 to 1957 a test of three amounts of N (39, 78 and 118 kg N/ha as 'Nitro-Chalk') was started on four groups of three plots, the N rates rotated round the plots of each set. The sets were:

Group	Past treatment	Plots
1	No P or K	1, 3, 7
2	PK	4, 6, 9
3	FYM	11b (divided into three sections)
4	Various	10a, 10b, 11a

During this period, 1943-57, plots 2, 5 and 8 in both experiments were fallowed each year, the crops were not even drilled, and the other plots had to be fallowed in five of these years which included 1956 and 1957. Table 5 shows the yields of wheat and barley

TABLE 5
Effect of nitrogen on wheat and barley on the Continuous Wheat and Barley experiments, Woburn, 1943-54

N kg/ha applied 1943-54	Grain and straw, t/ha, at 85% dry matter							
	Plots and treatments applied 1877-1926							
	1, 3, 7		4, 6, 9		10a, 10b, 11a		11b	
	no P grain	no K straw	PK grain	PK straw	various grain	various straw	FYM grain	FYM straw
	Wheat on the Continuous Wheat experiment ^a							
39	1.04	2.42	1.19	2.36	1.08	2.65	1.39	2.84
78	1.23	2.67	1.74	3.06	1.36	2.70	1.66	3.28
118	1.52	2.95	1.82	3.20	1.67	3.01	2.04	3.69
	Barley on the Continuous Barley experiment ^a							
39	0.70	1.33	0.90	1.81	0.73	1.66	1.13	2.54
78	0.93	1.61	1.39	2.31	0.89	1.84	1.24	2.40
118	1.10	1.72	1.37	2.04	0.82	1.63	1.44	2.80

(a) In some years the crops were a total failure or were so poor that the yields were rejected. Wheat yields are averaged over seven years 1944, 1945, 1949, 1951-54. Barley yields are averaged over six years 1943-46, 1952, 1953. In 1952 no yield of barley was recorded for plot 10a, an estimated value has been used here.

grain and straw in this period for those years when the crops were large enough to harvest. Yields of wheat increased up to the largest amount of N tested. The largest yields of barley were given by the middle dressing, 78 kg N/ha, except where FYM was given between 1877 and 1926; here barley responded up to the largest amount of N tested. Residues of P and K applied either as fertiliser or in FYM between 1877 and 1926 also increased yields in this experiment.

Between 1955 and 1957 individual plots received various amounts of ground chalk to bring the soils on all plots to pH 6. Having brought the surface soils to somewhere near their original soil reaction, an experiment began in 1959, with winter wheat and spring barley grown side by side on every plot, to compare the yields of each crop grown on the Wheat and the Barley experiments. The experiment continued in 1960 and 1961 but in 1961 spring wheat was grown. In 1959-60 the wheat and barley both received 112 kg N/ha to all plots. Table 6 shows the average yields of grain and straw in these two years, for the same groups of plots as in Table 5. Table 6 shows that yields in 1959-60 were about twice those in 1943-54 when comparable amounts of N were given. In 1959-60 wheat yielded better on the Barley experiment than on the Wheat experiment and barley better on the Wheat experiment than on the Barley experiment. To what extent this

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TABLE 6

Effect of residues of PK fertilisers and FYM on wheat and barley on the Continuous Wheat and Barley experiments, Woburn, 1959-60

	Grain and straw, t/ha, at 85% dry matter							
	Plots and treatments applied 1877-1926							
	1, 2, 3, 7		4, 5, 6, 8, 9		10a, 10b, 11a		11b	
	no P	no K	PK		various		FYM	
	grain	straw	grain	straw	grain	straw	grain	straw
Winter wheat ^a								
Wheat experiment	2.12	2.92	2.36	3.35	2.60	2.98	3.11	3.93
Barley experiment	3.10	4.07	3.05	4.68	3.28	4.33	3.51	5.37
Spring barley ^a								
Wheat experiment	2.46	1.82	3.02	2.28	2.42	1.53	3.01	2.08
Barley experiment	2.30	1.48	2.70	1.93	2.40	1.49	2.99	1.88

(a) Both wheat and barley given 112 kg N/ha each year.

reflected differences in disease or fertility between the two experimental sites is not known. In 10 of the 12 comparisons yields were increased by residues of P and K accumulated between 1877 and 1926 from fertilisers or FYM.

During 1960-62 a microplot experiment tested in much greater detail the value of the PK residues accumulated during the Classical experiments on parts of plots 7, 8, 9 and 11 of both experiments. The results are discussed by Johnston, Warren and Penny (1970).

The experiments were followed in 1963 and again in 1965-66. Oats were grown in 1962 and spring beans in 1964 on both experiments. Yields of bean grain ranged from 2.40 t/ha on plots unmanured since 1877 to 2.46 t/ha and 3.24 t/ha on plots with residues of P and K accumulated from fertiliser and FYM dressings respectively given between 1877 and 1926.

P and K removed by the crops. The percentage of P and K in the grain and straw has been determined in very few, if any, of the crops grown in these experiments. However, crops grown under similar conditions at both Woburn and Rothamsted have been analysed and, over a period of years, %P and K varies little from the following:

Crops given	% element in dry matter			
	Winter wheat		Spring barley	
	grain	straw	grain	straw
no P	0.35	0.06	0.34	0.06
P fertiliser	0.38	0.06	0.35	0.05
no K	0.42	0.30	0.45	0.55
K fertiliser	0.42	0.38	0.44	0.60

Using these values estimates of the P and K removed in the grain and straw have been calculated for three periods between 1877 and 1961 and the total for the whole period. Table 7 shows the uptake of P by both wheat and barley; Table 8 the uptake of K.

In 1966 it was decided that the sites of both experiments should be divided and made available for new experiments. Three sections were made (see Fig. 1):

1. Stackyard I, the south-east third (plots 7, 8, 9 and part of 11a and 11b of both experiments). An experiment comparing cereals grown continuously and in rotation was started in 1967. The effects of magnesium on the cereals, potatoes and leys grown in this experiment were discussed by Bolton and Slope (1971).

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TABLE 7

P, kg/ha, removed in the grain and straw of wheat and barley grown in the Continuous Wheat and Barley experiments, Woburn, 1877-1961

		Continuous Wheat experiment											
		1877-1926			1929-42			1943-54 and 1959-61			1877-1961		
Plot	Treatment ^a	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
1	Unmanured	108	35	143	16	7	23	46	13	59	170	55	225
2	N ^b	156	46	202	10	4	14	20	4	24	186	54	240
3	N* ^b	186	62	248	18	6	24	46	13	59	250	81	331
4	P K Na Mg	120	37	157	29	10	39	61	14	75	210	61	271
5	N P K Na Mg	250	67	317	20	7	27	25	4	29	295	78	373
6	N* P K Na Mg	259	75	334	28	9	37	61	14	75	348	98	446
7	Unmanured	121	36	157	18	7	25	46	13	59	185	56	241
8	N P K Na Mg	210	56	266	11	4	15	25	4	29	246	64	310
9	N* P K Na Mg	211	65	276	25	9	34	61	14	75	297	88	385
10a	N* P	173	48	221	18	5	23	51	13	64	242	66	308
10b	Rape cake	231	64	295	17	5	22	51	13	64	299	82	381
11a	N* K	163	49	212	26	9	35	51	13	64	240	71	311
11b	FYM	254	76	330	34	12	46	67	16	83	355	104	459
		Continuous Barley experiment											
1	Unmanured	125	30	155	16	6	22	40	9	49	181	45	226
2	N ^b	162	37	199	12	4	16	24	4	28	198	45	243
3	N* ^b	201	49	250	17	6	23	40	9	49	258	64	322
4	P K Na Mg	149	26	175	18	5	23	49	10	59	216	41	257
5	N P K Na Mg	223	40	263	12	3	15	27	5	32	262	48	310
6	N* P K Na Mg	281	54	335	28	6	34	49	10	59	358	70	428
7	Unmanured	119	27	146	15	5	20	40	9	49	174	41	215
8	N P K Na Mg	214	39	253	15	4	19	27	5	32	256	48	304
9	N* P K Na Mg	269	52	321	35	9	44	49	10	59	353	71	424
10a	N* P	187	34	221	17	5	22	39	9	48	243	48	291
10b	Rape cake	219	40	259	8	3	11	39	9	48	266	52	318
11a	N* K	227	51	278	26	9	35	39	9	48	292	68	360
11b	FYM	308	56	364	34	9	43	53	12	65	395	76	471

(a) For details of treatments see Tables 3 and 4.
 (b) N Nitrogen applied as ammonium sulphate.
 N* Nitrogen applied as sodium nitrate.

TABLE 8

K, kg/ha, removed in the grain and straw of wheat and barley grown in the Continuous Wheat and Barley experiments, Woburn, 1877-1961

		Continuous Wheat experiment											
		1877-1926			1929-42			1943-54 and 1959-61			1877-1961		
Plot	Treatment ^a	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
1	Unmanured	130	174	304	20	34	54	57	72	129	207	280	487
2	N ^b	187	229	416	12	18	30	26	24	50	225	271	496
3	N* ^b	224	310	534	22	28	50	57	72	129	303	410	713
4	P K Na Mg	133	231	364	32	66	98	69	99	168	234	396	630
5	N P K Na Mg	277	426	703	23	44	67	30	34	64	330	504	834
6	N* P K Na Mg	251	474	725	31	55	86	69	99	168	351	628	979
7	Unmanured	145	180	325	22	35	57	57	72	129	224	287	511
8	N P K Na Mg	232	356	588	12	24	36	30	34	64	274	414	688
9	N* P K Na Mg	233	403	636	28	56	84	69	99	168	330	558	888
10a	N* P	192	240	432	20	25	45	62	72	134	274	337	611
10b	Rape cake	256	404	660	18	32	50	62	72	134	336	508	844
11a	N* K	195	313	508	31	55	86	62	72	134	288	440	728
11b	FYM	281	479	760	37	77	114	76	109	185	394	665	1059
		Continuous Barley experiment											
1	Unmanured	166	277	443	22	51	73	51	70	121	238	397	635
2	N ^b	214	337	551	16	40	56	30	26	56	260	402	662
3	N* ^b	266	449	715	22	51	73	51	70	121	339	570	909
4	P K Na Mg	187	316	503	23	58	81	46	100	146	256	474	730
5	N P K Na Mg	280	486	766	15	40	55	19	37	56	314	563	877
6	N* P K Na Mg	354	648	1002	35	77	112	46	100	146	435	825	1260
7	Unmanured	157	249	406	20	48	68	51	70	121	228	366	594
8	N P K Na Mg	268	470	738	19	43	62	19	37	56	306	550	856
9	N* P K Na Mg	338	629	967	44	103	147	46	100	146	428	833	1261
10a	N* P	241	379	620	22	55	77	49	75	124	312	509	821
10b	Rape cake	275	485	760	10	39	49	49	75	124	334	599	933
11a	N* K	293	510	803	33	87	120	49	75	124	376	672	1048
11b	FYM	388	670	1058	43	103	146	64	119	183	495	892	1387

(a) For details of treatments see Tables 3 and 4.
 (b) N Nitrogen applied as ammonium sulphate.
 N* Nitrogen applied as sodium nitrate.

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2. Stackyard II, the centre third (plots 4, 5, 6 and parts of 11a, 11b, 10a, 10b of both experiments). This was allocated for experiments on soil structure. A small area of this site was used from 1962 onwards for a microplot experiment. The larger part was fallowed from 1967 to 1971 and then sown to a grass-clover ley in September 1971.
3. Stackyard III, the north-west third (plots 1, 2, 3 and part of 10a and 10b of both experiments). An experiment testing various amounts of phosphorus was started in 1968.

The Rotation experiments

These were made on four blocks, each of 4 acres (1.6 ha) and occupied much of the rest of Stackyard Field. The blocks have been distinguished as follows:

Initially, Latterly,	Rotation Series	I A	II B	III C	IV D
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The first experiment tested the residual manurial value of cake and corn fed to animals either in yards or on the land. Each block was divided into four 1-acre (0.4 ha) plots to test four treatments. These were the manures from a 'rich' feedingstuff, decorticated cotton cake (6.7% N), and a 'poor' one, maize meal (1.4% N), and these were compared with NPKMg fertilisers supplying the same amount of nutrients as in the manure from the two feedingstuffs. From 1877 to 1910 one crop of the four-course rotation: roots, barley, seeds-hay, wheat, was grown each year on each block. In 1911 the experiment was considerably modified and continued on blocks III and IV only. The same four crops were grown in rotation, but only two of them each year. The experiment stopped on these two blocks after the wheat crop in 1936 on Rotation IV and that in 1937 on Rotation III. The plots, particularly those given cake or equivalent fertilisers, were well manured at the start of the experiment. Between 1885 and 1902 there was a deliberate attempt to run down the fertility of the soils to try to show, in subsequent years, the alleged superiority of cake over corn feeding. The manuring between 1902 and the early 1960s would not now be considered excessive. Russell and Voelcker (1936) discussed the results in detail.

As each block was taken out of the Rotation experiment it has been used for other experiments.

1. **Series A.** From 1911 to 1967 there was a sequence of green manuring experiments.

a 1911-35, a two-year rotation testing the effects of green manures on the yields of winter wheat. The green manures were usually fed off by sheep receiving supplementary cake feeding.

b 1936-53, a two-year rotation testing the effects of green manures on the yields of kale (later cabbages) and barley. The green crops, either undersown in the previous year's barley or spring sown, were ploughed in during July for July-sown kale followed by barley the following spring.

c 1954-63, the effects of green manures on the yields of early potatoes and barley were tested.

d 1964-67, only barley was used to test the effects of green manures because yields of potatoes were affected more by eelworm than by the treatments being tested.

The early green manuring experiments were discussed by Russell and Voelcker (1936). The results were reassessed and the later experiments were discussed by Crowther and

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Mirchandani (1931), Crowther and Mann (1933), Mann (1958, 1959), Barnes and Clarke (1963), Chater and Gasser (1970) and Dyke (1973).

Series A was halved in 1968:

Series AI, south-east half, was reserved for experiments on root growth.

Series AII, north-west half, was reserved for experiments testing nematicides.

2. Series B

a 1911-16. The series was halved, one half grew lucerne, the other a grass-clover sward.

b 1917-29. Mainly arable crops were grown with a test of liming materials on the half following the grass-clover sward.

c 1930-60. The Six-Course Rotation experiment. The Series was divided in six blocks, one for each of the six crops, sugar beet, barley, clover, wheat, potatoes, rye, grown each year. The results were discussed by Yates and Patterson (1958).

d 1961-64. Arable crops, mainly non-experimental.

e 1965-74. The Organic Manuring experiment. The effects of the treatments on yields, nutrient balance and nutrient reserves in the soils during 1964-72 were discussed by Mattingly (1974) and Mattingly, Chater and Poulton (1974).

3. Series C

a 1937-59. Arable cropping, mainly non-experimental.

b In 1960 the Series was sub-divided for amongst others: The Reference Plot experiment, 1960-74 (Widdowson & Penny, 1967; Widdowson, Penny & Williams, 1967; Widdowson & Penny, 1972).

The Long-term Liming experiment, 1962-74 (Bolton, 1971).

4. Series D

a 1938-74. The Ley-Arable experiment. The effects of the treatments on the yields of the crops were discussed by Mann and Boyd (1958) and by Boyd (1968). Long-term changes in the organic matter content of the soil were given by Johnston (1973).

Summary

1. Experiments made on Stackyard Field, Woburn, between 1877 and 1974 are given together with details of the cropping, manuring and yields in the Continuous Wheat and Barley experiments.

2. Yields of wheat and barley in the Continuous experiments showed responses to N and PK in the early years of the experiment. However, during the course of the experiment the acidity of the soil increased, especially quickly where ammonium sulphate was used. The soils became so acid that the yields of both wheat and barley diminished and as yields decreased the amount of weeds on the plots increased. Chalking improved cereal yields.

3. After 1926 no further dressings of P and K were given either as fertilisers or as FYM in the Continuous Wheat and Barley experiments. When a test of amounts of N was made between 1943 and 1954 both wheat and barley responded to N and there was a benefit from the PK residues accumulated between 1877 and 1926.

4. Dressings of chalk were given on the Continuous Wheat and Barley experiments

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between 1955 and 1957 to bring the surface soils of all plots to pH 6. During 1959-60 winter wheat and spring barley given basal N fertiliser were grown side by side on all plots of both experiments. Wheat yielded better on the barley experiment than on the wheat experiment, barley better on the wheat experiment than on the barley experiment. Whether this was due to differences in soil fertility or disease on the two experiments is not known.

5. Estimates of the amounts of P and K removed in the crops are given.

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