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3. THE BROADBALK YIELDS

H. V. GARNER and G. V. DYKE

The yields on Broadbalk need to be considered in three parts. During the first eight years, 1844–51, Lawes and Gilbert changed the treatments on individual plots to test specific points suggested by previous results. They learnt much from these early experiments but had difficulties in interpreting some results because of the then unknown residual effects of the various materials used. By 1852 they had decided on a set of treatments likely to give clear answers to most of the important questions raised by the earlier work and the experiment entered its second phase, 1852–1925, during which each plot retained its assigned treatment with very little change. The actual dressings per acre and certain modifications made as the experiment proceeded are given in Tables 2·1 and 2·2. The third period began in 1926 when the traditional method of weeding the plots by hand gave way to a fallow at regular intervals. The manurial treatments were kept as before, but continuous wheat was replaced by a five-year cycle consisting of one year bare fallow followed by four years under wheat. The field was divided transversely into five sections to test each phase of the cycle every year and by 1935 the new scheme was established in full cycle. This arrangement, continued till 1967, provided results for six complete cycles. Recently wheat has once more been grown as a continuous crop on two sections while still retaining full information on the fallow effects. Yields for 17 successive crops have been recorded from one section and for nine crops on another. The continuous wheat has been sprayed with herbicides as required, with the materials shown in Table 2·2.

One of the main practical objects of the Broadbalk experiment was to measure the long period effects of organic manures and inorganic fertiliser on the growth of wheat. In individual years yields are affected by some unpredictable factors, such as the weather at critical periods, or the attack by pests or birds. To smooth out effects of such factors the yields in the following summary are usually averages over ten years or more. They estimate the results likely to be obtained from specific schemes of manuring over a period of years. The effects on yield of some pests and diseases are described in other articles.

Yields recorded. From 1844 until the combine harvester was first used in 1957, the produce of each plot was stooked in the field, carted to stack and threshed during the winter. Under this system the grain and straw usually contained about 85% dry matter and the yields were recorded as weighed. The following information was obtained: dressed grain in bushels; weight of a bushel of dressed grain in pounds; offal grain in pounds; total grain in pounds; straw, cavings and chaff in pounds, together giving a figure for total straw.

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Yields taken after combine harvesting were total grain as delivered from the combine and straw as picked up by the baler. (The yield of grain was strictly first-grade grain; the amount of small and broken grain dressed out by the combine harvester with weed seeds and rubbish is very small and has been neglected.) These weights were calculated to 85% dry matter for tabulation. Since 1965 the proportion of weed seeds and rubbish in the grain from the combine has been determined for certain plots (see Thurston, p. 200). The straw yields did not contain chaff, which remained on the plots. Yields of total grain and total straw, usually averaged over 10 years and for whole periods, are given for each stage of the experiment in Tables 3·16, 3·17 and 3·18.

The preliminary period, 1844–1851

The first paper containing yields obtained on Broadbalk was published after the experiment had been running for three years (Lawes, 1847), some of the main results are summarised below. When the first wheat crop in the experiment was drilled in the autumn of 1843, the Broadbalk field was in a poor state of fertility, for it had already grown four grain crops without manure (for details see Johnston & Garner, p. 14). It was therefore a suitable site for testing whether inorganic salts* supplying most of the constituents of plant ash could restore the fertility or whether materials providing combined nitrogen were also necessary. Strong hints to the answer came from the plots harvested in 1844: the yields from some of the key treatments (expressed in modern units) are given in Table 3·1.

TABLE 3·1

Broadbalk, first wheat crop, 1844

Yields of total grain and total straw cwt/acre

Treatment/acre	Grain	Straw
No manure	8·2	10·0
14 tons FYM	11·4	13·2
Ashes of 14 tons FYM	7·9	9·9
'Mineral manures' only[1]	9·0	10·3
'Minerals'[2] + 65 lb ammonium sulphate	11·4	12·7

[1] Average of 9 plots } with various mixtures of ash constituents.
[2] Average of 3 plots }

Although the yield without manure was very small, the mineral constituents, supplied either as the ashes of farmyard manure or as mixtures of inorganic salts, improved yield little, whereas a small amount of ammonium sulphate, providing only 12 lb of N, added to the minerals produced a crop equal to that given by a heavy dressing of FYM.

* Much of Lawes and Gilbert's argument with Liebig on the sources of nitrogen for plants was, in part, confused by lack of agreement on the meaning of various terms in use. Lawes and Gilbert were, however, consistent in their use of the word 'minerals' to describe the inorganic salts of those elements found in plant ash. Thus today, although ammonium sulphate and sodium nitrate, because they are inorganic salts, would be considered as mineral manures, in the early part of this article the phrase 'mineral manures' is used as by Lawes and Gilbert, to mean inorganic salts of phosphorus, potassium, sodium and magnesium, 'complete minerals' being a mixture containing all four elements.

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Two years later another important result emerged: the good effect of ammonium salts seemed to be exhausted by a single crop, and little or nothing remained for the crop that followed. The yields, expressed as increases above those from the unmanured plots, are in Table 3·2.

TABLE 3·2

Effect of ammonium salts in the year of application and the residual effect in the following year. Broadbalk, plot 10b, 1844–46

Increase above the unmanured level, cwt/acre

Year	Treatment/acre	Grain	Straw
1844	Minerals only (PK)	+0·8	−0·1
1845	3 cwt ammonium salts	+4·8	+13·9
1846	No manure	0·0	−0·5

These indications were studied during the next five years, large dressings of nitrogenous manures were given and a second paper on the results of the first seven seasons was published. (Lawes & Gilbert, 1851). The importance of nitrogen was confirmed but there were signs that plots manured with ammonium salts alone were beginning to need a supplement of mineral manures to produce a full crop. Over a seven-year period, yields with nitrogen and minerals together were at least as good as with farmyard manure. Only part of the applied nitrogen was accounted for in the increased produce.

The middle period, 1852–1925

This was a time of stability in management and a revised set of manurial treatments. It has two parts. For 48 years Gilbert maintained strict control of all operations on the plots, and to ensure the validity of the results made great efforts to keep down weeds. Several massive papers discuss the results obtained during this phase of the experiment. One, of 140 pages, gave a year-by-year account of the first 20 crops, with full yields of grain and straw and some measurements of quality; this covered the preliminary period and the first twelve years of the permanent scheme (Lawes & Gilbert, 1864). A further 20 crops were recorded in similar detail and discussed in relation to the unexhausted residues of manures and the fate of nitrogen and mineral constituents added to the soil in excess of crop requirements. This paper ended with a 24-point summary of the findings of the experiment up to 1883. (Lawes & Gilbert, 1884) The review was extended to a further ten years in Gilbert's lectures to the Association of American Experiment Stations in 1893 (Gilbert, 1895). The yield figures in this necessarily brief summary were confined to dressed grain in bushels, for it also gave chemical information about the recovery of added nitrogen by wheat and the uptake of P, K and Na in relation to the manures applied. This was the last of Lawes and Gilbert's papers dealing specifically with the Broadbalk experiment.

For the first quarter of the present century the Classical plots were directed first by A. D. Hall and then by E. J. Russell. However, the tradition of careful work and first priority for the Classical experiments was easily main-

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tained, for people trained under the old regime, notably Edwin Grey the Field Superintendent, continued to be responsible for the field work. Machinery gradually replaced hand labour, but the manuring was adhered to even more rigidly than before, except that Hall introduced an extra plot on Broadbalk (No. 20) on which only superphosphate was omitted from the complete manure.

The third period, 1926–1967

It had always been difficult to keep the plots clean, and labour problems during and after the First World War increased the difficulties and ultimately led to the end of continuous cropping and the introduction of the fallow system (for details see Table 2·2).

Broadbalk in relation to other early experiments

When the general trend of the results from the Broadbalk experiment became clear in 1852, Lawes decided to repeat some of the key treatments on other farms and on a second field on his own farm—Hoosfield, adjoining Broadbalk—with results given in Table 3·3 as mean yields for the periods specified. The Continuous Wheat experiment at Woburn was closely modelled on Broadbalk and the results of the first 10 years are given.

TABLE 3·3

Effect of the key Broadbalk treatments on the yield of wheat on several farms

Yields of dressed grain and total straw, cwt/acre

	Rothamsted Broadbalk	Rothamsted Hoos	Holkham, Norfolk	Rodmersham Kent	Woburn Befordshire
	Clay loam	Clay loam	Sandy loam	Clay	Sandy loam
	1856–63	1856–63	1852–54	1856–59	1877–86
Grain					
No manure	8·8	8·3	9·9	14·0	8·6
'Mineral manures' only	10·6	8·8	10·7	15·7	9·0
Nitrogen only	13·1	14·4	14·6	17·1	12·8
'Mineral manures' and nitrogen	21·5	20·5	18·4	18·0	16·3
Straw					
No manure	14·5	13·0	11·6	29·8	17·4
'Mineral manures' only	16·1	13·6	15·2	35·3	18·2
Nitrogen only	22·6	24·2	20·0	42·8	24·8
'Mineral manures' and nitrogen	37·3	35·9	25·3	50·9	32·0

The 'mineral manures' were the PKNaMg as used at Rothamsted: the nitrogen was 400 lb of ammonium salts, except at Woburn where it was 200 lb.

Broadbalk and Hoosfield gave strikingly similar results: everywhere yields were considerably greater from nitrogen than from 'mineral manures', but nitrogen usually gave greater increases in both grain and straw with 'mineral manures' than when used alone. The soil at Rodmersham was much more fertile than the others and responded less to nitrogen, but even there nitrogen produced more wheat than 'mineral manures'. These experiments suggested the broad principles of wheat manuring that

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are still valid; subsequent work has refined them to suit changing conditions.

The results 1852–1967

The results were reviewed from time to time. A masterly summary by Hall of all the field experiments and some of the associated chemical work was published (1905) and was brought up to date to include the Broadbalk yields up to 1912 by Hall and Russell (Hall, 1917). Wheat growing at Rothamsted, and on Broadbalk in particular, was again reviewed by Russell and Watson (1940), whose tables for yield of total grain in cwt/acre averaged over ten-year periods 1852–1921 are included in Tables 3·16 and 3·17.

The yields from the cumulative treatments applied to the Broadbalk plots provide information on the following points: (i) Comparison of farmyard manure with inorganic salts providing NPKNaMg; (ii) Effect of ammonium salts with and without PKNaMg; (iii) Effects of different amounts of ammonium salts; (iv) Comparison of ammonium and nitrate nitrogen; (v) Effect of time of applying ammonium salts; (vi) Residual effects of ammonium salts and of PKNaMg.

The yields bearing on these six points are divided into three sections. The first covers the main period of the experiment 1852–1925, during which the main questions were answered for continuous wheat. The second section shows how the fallow system affected the results, with yields given as the yearly means of all four phases averaged over six cycles. The third section covers the whole period of the experiment, and the yields quoted from 1935 onwards are those obtained in the fourth year after fallow, to bring them roughly in line with the previous continuous cropping.

Comparison of farmyard manure with complete fertilisers. Farmyard manure at 14 tons/acre has been applied to plot 2B since autumn 1843.

TABLE 3·4

Comparison of yields of wheat grown with annual applications of farmyard manure (FYM), with complete inorganic fertilisers supplying 86 lb N (N_2) plus PKNaMg (symbol C) or 129 lb N (N_3) plus C, Broadbalk, 1852–1967

Total grain cwt/acre

Plot	Treatment	Continuous wheat 1852–1925	6 fallow cycles 1935–64	Whole period 1852–1967
3	None	6·7	11·3	7·7
2B	FYM	19·4	22·7	19·5
7	N_2C	17·6	19·7	17·7
8	N_3C	20·1	22·1	20·1
FYM minus N_2C		+1·8	+3·0	+1·8
FYM minus N_3C		−0·7	+0·6	−0·6

In all tables containing means for 1935–64 or 1852–67 the following conventions have been observed:

1935–64 means of 1st, 2nd, 3rd and 4th crop after fallow (in 1963 the 1st crop after fallow on plots 10, 11, 12 and 14 failed and the yields have been taken as zero—see p. 39).

1852–1967: from 1935, 4th crop after fallow only.

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Table 3·4 compares yields from FYM with those from two 'complete' mixtures of inorganic salts, each providing the same amount of PKNaMg, one (N_2) with 86 lb N and the other (N_3) with 129 lb N/acre as ammonium salts, tested each year since 1852.

The FYM was not analysed, but from the composition of many other samples it was assumed that 14 tons contained 200 lb N; 30 lb P; 140 lb K. The 'mineral manures' PKNaMg provided nearly the same amount of phosphorus and a little more than half the K contained in the FYM. N_2 had only 43%, and N_3 64% of the total N of the FYM. These four plots provide a very important result. They showed that, over a long period of years on a clay loam soil, mixtures of inorganic salts of the type tested could maintain much the same yield of grain as large dressings of FYM. The mixture of PKNaMg with 86 lb N produced slightly less, but PKNaMg with 129 lb N, although it frequently lodged the crop, produced almost the same yield as FYM. During the fallow period yields on the unmanured plot were 17% more than previously, but on average all the manured plots were only 11% more. Hence differences between FYM and fertilisers were almost unchanged, although the increases they produced over no manures were slightly less under the fallow system. This comparison has rarely been repeated, but at two farms where it was made for many years the results were similar. For the first 30 years at Woburn, 1877–1906, yearly dressings similar to those on Broadbalk were used on continuous wheat: N_2PKNaMg (82 lb N) gave 17·4 cwt grain/acre whereas FYM (105 lb N) yielded 14·0 cwt. At Saxmundham, 6 tons/acre of FYM have been used yearly since 1899 in a four-course rotation (Rotation I) and in the recent ten year period 1956–65 the wheat crop was 22·6 cwt with FYM and 23·3 cwt with a fertiliser mixture providing 34 lb N. (*Rothamsted Report for 1965*, p. 233.)

Effect of ammonium salts and complete 'mineral manures'. Table 3·5 shows the yields obtained with ammonium salts (N_2) and complete 'mineral manures' (PKNaMg) when used singly and in combination. The earliest results on Broadbalk suggested that ammonium salts were much more effective for wheat than any combination of ash constituents tested and this was amply confirmed as the experiment continued. Thus the

TABLE 3·5

Comparisons of yields of wheat grown with ammonium salts (N_2) and complete mineral manure (PKNaMg, symbol C) used separately and together. Broadbalk, 1852–1967

		Total grain cwt/acre		
Plot	Treatment	Continuous wheat 1852–1925	6 fallow cycles 1935–64	Whole period 1852–1967
3	None	6·7	11·3	7·7
5	C	7·8	12·8	9·0
10	N_2	10·9	16·6	12·6
7	N_2C	17·6	19·7	17·7
N_2 minus None		+4·2	+5·3	+4·9
N_2C minus C		+9·8	+6·9	+8·7
Difference		+5·6	+1·6	+3·8

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average of 74 crops showed that whereas N_2 alone increased grain yield by 4·2 cwt, PKNaMg alone increased it by only 1·1 cwt/acre. Table 3·5 brings out the important point that the nitrogen was still more effective when PKNaMg were also added, for the increase given by N_2 was then 9·8 cwt.

The effect of fallow was seen chiefly in treatments that gave small yields under continuous wheat, where the increase was about 5 cwt grain, or 50–70%. The completely fertilised plot produced a fairly good crop even under the old system and its yield was increased by only 2·1 cwt or 12% by fallow. The general pattern of responses was the same under the fallowing system as before, but the actual increase from the complete fertiliser N_2C was slightly less and also the size of the interaction between N_2 and C.

Effect of increasing levels of ammonium salts. A test of ammonium salts at 0, 21·5, 43, 86, 129 and 172 lb N/acre (800 lb ammonium salts) in the presence of PKNaMg was begun in 1852 and continued for 13 years. Up to 86 lb N/acre, the ammonium salts were very effective in increasing the weight of both grain and straw and the rate of increase was roughly proportional to the amount employed, but 129 lb N and 172 lb gave only trivial further increases in grain although the straw still responded. After 1864 the smallest and largest dressings were omitted, but the three intermediate ones have been continued ever since.

TABLE 3·6

Increases in yield of wheat grain and straw given by ammonium salts at three rates (N_1, N_2, N_3) applied in different ways. All plots receive PKNaMg (symbol C) in autumn. Broadbalk, 1852–1964

Total grain and total straw, cwt/acre

Plots	Yield with C only 5		Increase for: 1st 43 lb N N_1C–C 6 minus 5		2nd 43 lb N N_2C–N_1C 7 minus 6		3rd 43 lb N N_3C–N_2C 8 minus 7	
Continuous wheat	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
All N in autumn 1852–77	8·8	13·5	+5·0	+9·1	+5·0	+10·8	+2·0	+6·4
All N in spring 1878–83	7·4	10·8	+5·1	+10·9	+4·8	+13·3	+2·2	+8·4
21·5 lb N in autumn, rest in spring 1884–1925	7·2	10·1	+4·4	+8·4	+5·3	+11·9	+2·8	+9·0
Six fallow cycles 1935–64								
21·5 lb N in autumn, rest in spring								
1st crop after fallow	18·7	32·2	+2·9	+7·2	+1·8	+6·3	+1·1	+3·2
Mean of 2nd, 3rd and 4th crops after fallow	10·8	18·5	+3·2	+6·4	+4·5	+9·8	+2·8	+9·6

The results in Table 3·6 are grouped according to the method of applying the ammonium salts and the state of fertility of the soil arising from bare fallowing. From 1852–77 all the N was given in autumn; from 1878–83 it was all applied in spring. Since 1884, 21·5 lb N has been given in autumn and the balance of the dressing in spring. The total amounts of N were 0, 43, 86, and 129 lb/acre. For the six fallow cycles the yields obtained in the first year after bare fallow have been shown separately.

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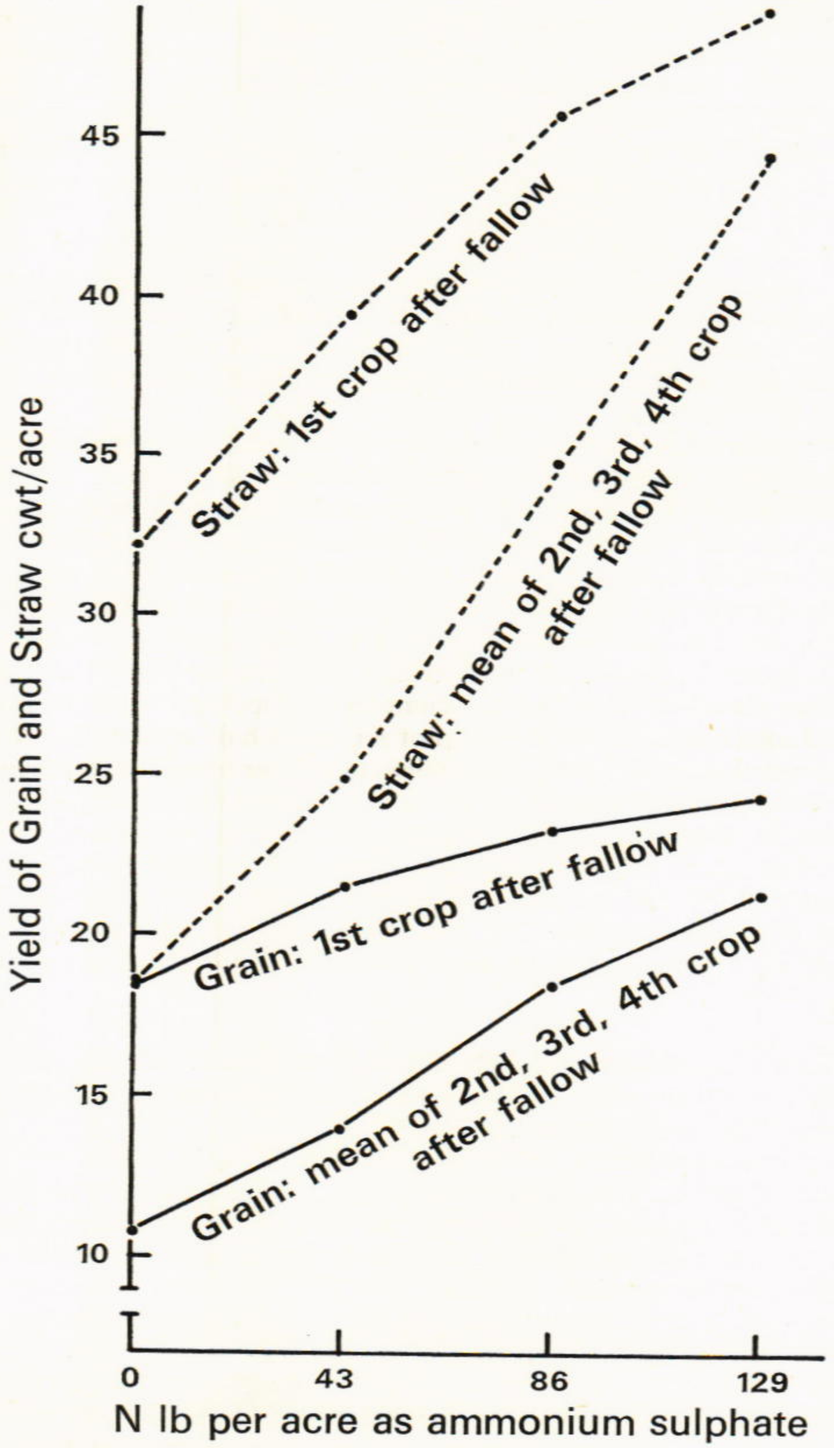

FIG. 3·1 Response curves for ammonium sulphate at 43, 86 and 129 lb N/acre. Grain (full lines) and straw (dotted lines) cwt/acre. First crop after fallow, and mean of 2nd, 3rd and 4th crops after fallow. Mean of 6 complete cycles, Broadbalk, 1935–64.

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In the first 26 years when all the N was given in autumn, and in the next six years when all was applied in spring, the grain yields and the increases for successive dressings of 43 lb N were very similar; 86 lb N gave almost exactly double the extra grain given by 43 lb N, but the further increase given by 129 lb N was relatively small.

When part of the N was given in autumn and the remainder in spring the second dressing of nitrogen was slightly more effective than the first, and the response to the heaviest dressing was smaller.

In the first year after fallow, the no-nitrogen yield was heavy and the increases in grain yields from fertiliser nitrogen, though small, followed a conventional response curve. In the 2nd, 3rd and 4th crops after fallow the responses in grain were very similar to those obtained from continuous wheat and here also the second dressing was slightly more effective than the first (see Fig. 3·1).

At every rate of N dressing the straw was increased more than the grain and the slope of the response curve was steeper throughout. The grain: straw ratio was 64% where no N was given and only 48% with 129 lb N/acre. Russell and Watson (1940) concluded that in the early years of the experiment when 6 amounts of N were tested the data were well represented by a quadratic curve. From 1884 onwards when part of the N was applied in autumn the second dressing of N gave slightly more grain and appreciably more straw than the first and this may be related to the fact that autumn N is less efficient than spring N (Table 3·8). This would tend to affect the yield from plot 6 (one half of its total N applied in autumn) more than that of plot 7 (one quarter of its N in autumn). Also the experiment is on single plots so that appreciable variation may be expected. The behaviour of levels of sodium nitrate (Table 3·7) was more normal: the first increment of 43 lb N when tested on continuous wheat gave an increase of 7·4 cwt grain and 15·6 cwt. straw and the second increment of N produced only 3·1 cwt grain and 9·5 cwt straw. In the fallow period the responses to the two levels of nitrate-N were almost linear.

Comparison of ammonium sulphate and sodium nitrate. Ammonium and nitrate nitrogen were compared each at two amounts of N in the presence of complete 'mineral manures'.

Plots given ammonium sulphate had 21·5 lb N in autumn and the remainder in spring. The smaller dressing of sodium nitrate was given in one application in spring, and the larger was put on in two separate applications in spring. Used in this way sodium nitrate always gave more grain than equivalent ammonium sulphate; this difference was even greater in the straw, which was heavier and brighter than with the corresponding amounts of ammonium. Averaging both dressings over the whole period of 83 years, nitrate nitrogen gave 1·8 cwt more grain and 4·4 cwt more straw/acre than ammonium nitrogen, increases of 11 and 16% respectively. During the first 41 years, when wheat was grown continuously, the advantage for nitrate was greater than this, especially from the smaller dressing, when the gain was 3·0 cwt grain and 7·3 straw. Fallowing increased the yield by an average of 3·8 cwt grain (28%) and 7·8 cwt straw (33%) but

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TABLE 3·7

Comparison of ammonium sulphate (N_1, N_2) and sodium nitrate (N_1, N_2*) at 43 lb and 86 lb N/acre in the presence of complete mineral manure (PKNaMg, symbol C). Broadbalk, 1885–1967*

Total grain and total straw, cwt/acre

		Continuous wheat 1885–1925		Six fallow cycles 1935–64		Whole period 1885–1967	
Plot	Treatment	Grain	Straw	Grain	Straw	Grain	Straw
5	C	7·2	10·1	12·8	21·9	9·1	14·3
6	N_1 C	11·6	18·4	15·9	28·5	12·8	22·0
7	N_2 C	16·8	30·3	19·7	37·5	17·4	33·0
9	N_1*C	14·6	25·7	17·0	30·5	14·9	27·2
16	N_2*C	17·7	35·2	21·6	40·5	18·8	36·7
	N_1 C minus C	+4·4	+8·3	+3·1	+6·6	+3·7	+7·7
	N_1*C minus C	+7·4	+15·6	+4·2	+8·6	+5·8	+12·9
	N_1*C minus N_1C	+3·0	+7·3	+1·1	+2·0	+2·1	+5·2
	N_2 C minus C	+9·6	+20·2	+6·9	+15·6	+8·3	+18·7
	N_2*C minus C	+10·5	+25·1	+8·8	+18·6	+9·7	+22·4
	N_2*C minus N_2C	+0·9	+4·9	+1·9	+3·0	+1·4	+3·7
	Mean difference N* C minus N C	+2·0	+6·1	+1·5	+2·5	+1·8	+4·4

the superiority of the nitrate remained. It was only slightly diminished for grain but more so for straw.

Ammonium salts applied in spring or in autumn. There were two slightly different approaches to the question of when to apply nitrogen: (i) The simple comparison of all the ammonium salts (86 lb N) applied in autumn or all in spring. This was tested for only 11 seasons, 1873–1883, and was then changed to (ii), all the nitrogen given in autumn or 21·5 lb N in autumn plus the remainder in spring. This arrangement continued till 1967, with results in Table 3·8.

TABLE 3·8

Yields with ammonium salts applied in the spring or in the autumn in presence of PKNaMg. Broadbalk, 1873–1964

Total grain and total straw cwt/acre

Quantity of N and time of application	Grain	Straw
1873–1883 Continuous wheat		
86 lb N spring	16·8	30·7
86 lb N autumn	14·5	25·5
Spring minus autumn	+2·3	+5·2
1892–1921		
21·5 lb N autumn, 64·5 lb N spring	16·9	30·7
86 lb N autumn	15·1	26·6
Spring minus autumn	+1·8	+4·1
1935–1964 Six fallow cycles		
21·5 lb N autumn, 64·5 lb N spring	19·7	37·5
86 lb N autumn	17·7	31·8
Spring minus autumn	+2·0	+5·7

On the average of the first 11 years, nitrogen applied in spring gave one sixth more grain and one fifth more straw than autumn nitrogen. There

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were highly contrasted seasons: 1878–79 was disastrously wet with nearly 10 in. of rain more than average; 1879–80 was exceedingly dry. The yields were:

	1878–79		1879–80	
	Grain	Straw	Grain	Straw
All N in spring	9·4	26·9	19·2	35·8
All N in autumn	3·3	8·1	20·4	35·9

The advantage of spring over autumn nitrogen is greatest in wet seasons; even rain in spring and early summer can lessen the value of autumn nitrogen ('Alumnus', 1932). When plot 7 received one quarter of its nitrogen in the autumn it was to be expected that the difference between the spring and autumn applications would be slightly less. The figures for 20 years under continuous wheat and a further 30 years under the fallow system show this, but the spring application was better by 2 cwt of grain and 5 cwt of straw, differences of 12 and 17% respectively.

The residual action of ammonium salts. One of the most striking demonstrations of fertiliser action that has passed a clear message to countless farmers who have visited Broadbalk was begun on plots 17 and 18 in 1852. These plots have received the same fertiliser as plot 7 (N_2PKNaMg) but divided into two parts, N_2 or PKNaMg. In even numbered years plot 17

TABLE 3·9

Effect of applying ammonium salts (N_2) and 'mineral manures' (PKNaMg, symbol C) in alternate years. Broadbalk, 1852–1967

Total grain and total straw, cwt/acre

		Continuous wheat 1852–1925		6 fallow cycles 1935–1964		Whole period 1852–1967	
Plot	Treatment	Grain	Straw	Grain	Straw	Grain	Straw
17/18(N)	N_2 (after C)	16·1	28·1	19·4	33·9	16·8	29·7
17/18(C)	(after N_2)	8·1	12·3	10·8	18·8	8·2	13·0
10	N_2 annually	10·9	17·8	16·6	26·7	12·6	20·4
5	C annually	7·8	11·5	12·8	21·9	9·0	14·0
7	N_2C annually	17·6	32·1	19·7	37·5	17·7	33·2
Differences from Plot 7:							
5	C only	−9·8	−20·6	−6·9	−15·6	−8·7	−19·2
10	N_2 only	−6·7	−14·3	−3·1	−10·8	−5·1	−12·8
17/18(N)	Direct N_2, residual C	−1·5	−4·0	−0·3	−3·6	−0·9	−3·5
17/18(C)	Direct C, residual N_2	−9·5	−19·8	−8·9	−18·7	−9·5	−20·2

had the nitrogen and 18 the PKNaMg, in odd years, plot 17 the PKNaMg and plot 18 the nitrogen. Thus, in any year, one plot grew wheat with a direct dressing of nitrogen plus the residues of previous applications of PKNaMg, while its neighbour had a direct dressing of PKNaMg plus the residues of previous dressings of ammonium salts. Table 3·9 compares the yields from each of these treatments with those obtained by continuous dressings of the same constituents alone and in combination.

The reference point for Table 3·9 is plot 7 which received ammonium salts N_2 and PKNaMg every year, and averaged 17·6 cwt grain/acre during the period of continuous wheat growing. The small yields on plots 5 and

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10 show that both nitrogen and PKNaMg together are necessary to produce this result. In the year the alternating plots got N, the yield is only 1·5 cwt less than on plot 7 showing that the residues of PKNaMg applied in alternate years since 1852 allow the full effect of the applied nitrogen. In the year the plots get PKNaMg only the yield is 8·1 cwt, or 9·5 cwt below that on plot 7, and little more than on plot 5 where nitrogen has never been applied. As P, K, Na and Mg are not lacking in this plot, the small yield must reflect the lack of any residual value from previous dressings of 86 lb N. Fallowing increased the yield, especially on plots that previously yielded least, but had no effect on the residual effects of ammonium salts and mineral fertilisers.

Effect of the mineral constituents PKNaMg. In the tables so far the ash constituents have been considered as a group, but when the experiment was arranged in its permanent form one group of plots tested the mineral constituents separately.

Superphosphate, given with a basal dressing of ammonium sulphate, gave a very small increase in grain and a little larger one in straw before fallowing was introduced and almost none thereafter. In 1906 plot 20 was started to show the effect of omitting superphosphate from the complete

TABLE 3·10

Effects of superphosphate (P) in the presence of ammonium salts (N_2) and effects of potassium (K), sodium (Na) and magnesium (Mg) in the presence of N_2P and of NaMg in the presence of N_2PK. Broadbalk, 1852–1967

Total grain and total straw, cwt/acre

		Continuous wheat 1852–1925		6 fallow cycles 1935–64		Whole period 1852–1967	
Plot	Treatment	Grain	Straw	Grain	Straw	Grain	Straw
10	N_2	10·9	17·8	16·6	26·7	12·6	20·4
11	N_2P	12·3	21·5	16·1	27·3	13·3	23·2
12	N_2P Na	15·7	26·9	17·8	30·5	16·2	27·7
13	N_2P K	17·0	30·7	18·7	35·3	16·9	31·6
14	N_2P Mg	15·5	26·9	18·0	31·1	16·1	27·9
7	N_2P K Na Mg	17·6	32·1	19·7	37·5	17·7	33·2
	N_2P minus N_2	+1·4	+3·7	−0·5	+0·6	+0·7	+2·8
	N_2P Na minus N_2P	+3·4	+5·4	+1·7	+3·2	+2·9	+4·5
	N_2P K minus N_2P	+4·7	+9·2	+2·6	+8·0	+3·6	+8·4
	N_2P Mg minus N_2P	+3·2	+5·4	+1·9	+3·8	+2·8	+4·7
	N_2P K Na Mg minus N_2P K	+0·6	+1·4	+1·0	+2·2	+0·8	+1·6

fertiliser (N_2PKNaMg) as used on plot 7, but the position of the new plot at the extreme edge of the field was unsatisfactory and it could not be brought into the fallow cycle, so a long period comparison with plot 7 is not possible. The comparisons of Na, K, and Mg, applied separately in chemically equivalent amounts were made under more favourable conditions than the test of superphosphate, for they had a basal dressing of both nitrogen and phosphate and the effects shown in Table 3·10 are increases above the basal level. Sodium and magnesium gave almost identical increases of grain and straw in both periods of the experiment: 3 cwt

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grain under continuous cropping and almost half as much afterwards. Potassium gave somewhat bigger increases throughout: during the period of continuous wheat, there was a gain of 4·7 cwt grain and the striking increase of 9·2 cwt in straw. Although this test showed that Na and Mg each increased the crop when tested on land deficient in K, they had very little effect when applied together, but in smaller amounts, on land that had received K for many years: omitting NaMg from the complete manure (N_2PKNaMg) shown in Table 3·10 as the difference between plots 7 and 13 resulted in a loss of less than 1 cwt grain/acre.

Rape cake. Except for farmyard manure, the only organic manure tested on Broadbalk was rape cake, the residue after expressing oil from the rape seed. The material used contained on the average 5·5% N, 2·2% P_2O_5, 1·3% K_2O. Dressings provided 86 lb N/acre, i.e. equivalent to N_2 as ammonium salts. In 1941 rape cake was no longer obtainable and castor meal, a very similar product with almost the same content of nutrients, has been used. Table 3·11 compares the yields of wheat obtained with rape cake alone with those from ammonium sulphate alone and ammonium sulphate plus mineral manures.

TABLE 3·11

Yields with rape cake or castor meal (R) compared with ammonium salts (N_2) and with ammonium salts plus 'mineral manures' (PKNaMg, symbol C) Broadbalk, 1879–1964

Total grain and total straw, cwt/acre

		Continuous wheat 1879–1925*		6 fallow cycles 1935–64	
Plot	Treatment	Grain	Straw	Grain	Straw
19	R	13·7	23·7	17·4	29·9
10	N_2	9·7	15·7	16·6	26·9
7	N_2C	17·0	31·2	19·7	37·5

* Omitting 1917–20 when no rape cake was obtainable.

In 43 years of continuous wheat, rape cake gave 4·0 cwt grain and 8·0 cwt straw more than equivalent N in the form of ammonium salts without any PKNaMg, but rape cake was not necessarily the better source of nitrogen because it supplied appreciable amounts of P and K and plot 19 received light dressings of superphosphate in the 27 years before 1879. When PKNaMg was applied with the ammonium sulphate on plot 7 the combination produced 3·3 cwt grain and 7·5 cwt straw more than rape cake.

All yields were increased by introducing the bare fallow, but those with N_2 much more than those with R, consequently the differences observed under the fallow system were smaller though still in the same direction as before.

The effects of the fallowing cycle 1935–64. The system of growing four successive wheat crops followed by one year's bare fallow became fully established in 1935; the transition from continuous cropping and some of the main effects of fallowing observed in the first 20 years has been summarised (*Rothamsted Report for 1955*, pp. 161–165). The yields of total

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grain and total straw for the four cropped phases are averaged over six cycles in Table 3·19.

The general effect of the fallowing system is seen by comparing the mean yield of the whole experimental area for each phase of the fallow cycle with the corresponding figure for (1) continuous wheat in the last ten-year period before fallowing started, and (2) the fourth year after fallow.

TABLE 3·12

Mean yields under the fallowing system (1935–64) compared with (i) the last ten years (1916–25) under continuous wheat and (ii) the mean yield (1935–64) in the fourth year after fallow. Average of all plots (excluding plot 20). Broadbalk, 1916–64

Total grain and total straw, cwt/acre

	Grain					Straw				
Years after fallow	1	2	3	4	Mean	1	2	3	4	Mean
Fallow system 1935–64	21·3	17·5	15·7	15·9	17·6	39·5	31·0	28·3	28·7	31·9
Increase over continuous wheat:										
actual	10·7	6·9	5·1	5·3	7·0	19·5	11·0	8·3	8·7	11·9
%	101	65	48	50	66	98	55	42	44	60
Increase over 4th year after fallow:										
actual	5·4	1·6	−0·2	—	1·7	10·8	2·3	−0·4	—	3·2
%	34	10	−1	—	11	38	8	−1	—	11

Table 3·12 shows that the percentage increases in grain and straw from fallowing were closely similar. The immediate effect of the fallow was to double the yields obtained in the final 10 years of continuous wheat, for the second crop in the cycle the increase was about two-thirds, and for the final two crops the increase was one half. The actual yields of grain and straw in the third and fourth years after fallow were similar at 15·8 cwt grain and 28·5 cwt straw; the yields in the first year after fallow were on the average one-third more than this, and in the second year after fallow one-tenth more. The results on individual plots show notable differences:

(i) The farmyard manure plots were the only ones in which the yield in the fourth year after fallow was appreciably less than in the third year. With nearly all the remaining 16 treatments, yields were slightly bigger in the 4th than in the 3rd crop. The 4th crop after fallow had slightly less severe eyespot (*Cercosporella herpotrichoides*) than the 3rd (see Glynne, p. 121).

(ii) Plots without potassium gave abnormally small yield increases in the first year after fallow; in fact when Na and Mg were also omitted, as in plots 10 and 11, the mean yield in the first year after fallow was less than in the second year. This effect partly reflects the damage caused by the Wheat Bulb fly (*Leptohylemyia coarctata*) which was greatest on the K-deficient plots. In 1963 the damage was so great that plots 10, 11, 12 and 14 were not harvested (see Johnson, Lofty & Cross p. 152).

(iii) Plots giving small yields gave bigger increases from bare fallow than the more productive ones. This is shown in Table 3·13 where the

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plots are grouped according to the quantity of ammonium- or nitrate-nitrogen supplied in the manure. The immediate effect of the fallow is measured by the difference in yield between the 4th and the 1st crop after fallow.

TABLE 3·13

Effect of quantity of fertiliser N on the increased yield obtained in the first year after bare fallow, Broadbalk, 1935–64

		Grain, cwt/acre			Straw, cwt/acre		
		Yield in fourth year after	Increase in first year after fallow		Yield in fourth year after	Increase in first year after fallow	
Plots	N lb/acre	fallow	actual	%	fallow	actual	%
3, 5, 17/18C	0	9·6	8·0	83	15·9	14·0	88
6, 9	43	14·8	6·8	46	26·6	12·9	48
7, 13, 16, 17/18N	86	18·5	4·9	26	33·6	11·0	33
8	129	20·6	3·9	19	42·9	6·0	14

Yield in the year immediately after the fallow was 8·0 cwt grain (or 83%) more on plots without N, and only 3·9 cwt (or 19%) where the full dressing of 129 lb N was given. Effects were similar but larger with yield of straw.

Continuous wheat once more. In 1956, when section I of Broadbalk had grown four wheat crops and was due to be fallowed, only half of the area was kept in the fallow cycle; the other half, next to the Wilderness, now called section IA, was assigned to continuous wheat and herbicides used as required to keep down the weeds (see Table 2·2). Twelve crops have since been grown under the new system. In 1963 the same was done on section V when continuous wheat was re-established on section VB next to the drain and five crops have now been grown. The changes in the yields, adjusted for seasonal differences, and the time trend of the chief treatment effects were examined for the 5th–12th crops of continuous wheat by Dyke (1964). Table 3·14 compares

(i) the average yield for each treatment under the new continuous system for the 12 years 1956–1967 with the mean yield obtained on the remainder of the field in the fourth year after bare fallow over the same period;

(ii) the mean yield of two complete fallow cycles, eight crops, on section IB, with the corresponding eight crops of continuous wheat on the adjoining section IA;

(iii) the average yield per acre per year, taken over two complete fallow cycles (ten years) on section IB, with the average of the corresponding ten continuous crops on section IA.

The first part of Table 3·14 gives the average yields of 12 crops of continuous wheat, the 5th–16th crops since the last fallow. They differ only slightly from those obtained in the fourth year of the fallow cycle. The mean yields of all treatments were 17·4 cwt grain/acre at the end of the fallow cycle and 17·9 cwt averaged over the 5th–16th continuous crops, so it

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TABLE 3·14

Broadbalk wheat: yields of newly established continuous wheat (section IA) compared with yields obtained under the fallowing system

Total grain, cwt/acre.

		1956–67			1957–65 (omitting 1961) Mean of 8 crops			Annual yield per acre Mean of ten years 1956–65		
Plot	Treatment	Continuous section IA	4th crop after fallow all sections	Difference	Continuous section IA	2 cycles section IB	Difference	Continuous 10 crops section IA	2 cycles 8 crops, 2 fallows section IB	Difference
2A	FYM[1]	20·9	21·4	+0·5	21·6	25·3	+3·7	20·7	20·2	−0·5
2B	FYM	21·4	22·1	+0·7	22·4	24·7	+2·3	21·6	19·8	−1·8
3	None	10·6	11·1	+0·5	10·8	12·8	+2·0	10·9	10·2	−0·7
5	P K Na Mg	12·1	13·6	+1·5	12·4	13·8	+1·4	12·6	11·1	−1·5
6	N_1 P K Na Mg	15·8	16·7	+0·9	15·7	16·9	+1·2	15·6	13·5	−2·1
7	N_2 P K Na Mg	21·5	19·6	−1·9	21·6	22·5	+0·9	21·0	18·0	−3·0
8	N_3 P K Na Mg	24·1	22·9	−1·2	24·6	24·7	+0·1	23·3	19·8	−3·5
9	N_1*P K Na Mg	17·8	16·5	−1·3	18·9	19·5	+0·6	17·6	15·6	−2·0
10	N_2	15·0	16·9	+1·9	15·9	18·1	+2·2	15·7	14·5	−1·2
11	N_2 P	18·9	15·7	−3·2	20·0	17·9	−2·1	18·5	14·3	−4·2
12	N_2 P Na	20·5	17·5	−3·0	20·8	19·7	−1·1	20·0	15·8	−4·2
13	N_2 P K	20·3	18·0	−2·3	20·7	21·8	+1·1	20·0	17·5	−2·5
14	N_2 P Mg	21·0	17·6	−3·4	21·2	20·8	−0·4	20·2	16·7	−3·5
15	N_2†P K Na Mg	17·5	16·4	−1·1	18·6	19·9	+1·3	18·2	15·9	−2·3
16	N_2*P K Na Mg	20·8	22·3	+1·5	22·4	22·6	+0·2	20·8	18·0	−2·8
17/18	N_2	18·6	19·6	+1·0	19·0	19·3	+0·3	18·2	15·5	−2·7
17/18	P K Na Mg	8·2	9·1	+0·9	8·5	10·2	+1·7	8·4	8·2	−0·2
19	R	17·5	16·1	−1·4	18·2	19·7	+1·5	17·5	15·8	−1·7
	Mean	17·9	17·4	−0·5	18·5	19·5	+1·0	17·8	15·6	−2·2

[1] Since 1885.

N Nitrogen as ammonium salts.
N* Nitrogen as sodium nitrate.
N† All nitrogen as ammonium sulphate in autumn.

seems that, after four crops are grown, the deterioration in the early years of continuous wheat is slow. The slight irregularities in the responses of the various treatments to the two systems are not clearly related to the nutrients applied, but are more likely to be because the comparisons are not balanced for position in the field.

The second part of Table 3·14 compares the yields obtained in the full sequence of four crops after fallow with those from continuous wheat on adjoining pieces of land, sections IA and IB. The advantage is then almost always with the fallowing system, for the large yields usual in the first year after fallow are included. The mean difference over 12 years and all treatments was 1·0 cwt grain/acre in favour of the fallowing cycle. There were differences between treatments, however, for plots 11 and 12 and to a lesser extent plot 14, all of which received N_2P but no K, yielded rather more in continuous wheat than in the fallow cycle; this is probably because on these plots the crops immediately after fallow were greatly damaged in seasons when wheat-bulb fly was prevalent.

When the average yields from each system are compared over a ten-year period, i.e. two complete cycles of the fallow system, with eight crops on section IB but ten on IA, Table 3·14 shows that yield per acre per annum is greater from the continuous wheat with herbicides. This advantage occurred in every treatment and averaged 2·2 cwt/acre or 14%.

Slow changes in the yields. Linear regressions on time have been calculated using ten-year means from 1852–61 to 1922–25. The calculations were done on the Orion computer using a programme of A.J.B. Anderson,

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whose help is acknowledged. There is little evidence of slow changes in the period of regular fallowing and regressions have not been calculated for this period. Table 3·15 shows the yields for 1852–61 and 1922–25 calculated from the regression lines together with the mean yields of the fourth crop after fallow for 1935–64.

TABLE 3·15

Slow changes in yields—Broadbalk

Grain, cwt/acre

Yields for early and late years of continuous wheat (calculated from regressions) and means for fallow period (4th crop after fallow)

Plot		1852–61	1922–25	1935–64
2B	FYM	21·0	17·0	20·0
3	None	8·6	4·4	9·5
5	P K Na Mg	9·8	5·4	11·4
6	N_1 P K Na Mg	15·4	8·9	14·2
7	N_2 P K Na Mg	20·3	14·2	18·0
8	N_3 P K Na Mg	22·5	16·8	20·6
9	N_1*P K Na Mg	17·9[1]	10·3	15·3
10	N_2	13·7	7·5	15·3
11	N_2 P	16·3	7·7	14·8
12	N_2 P Na	19·6	10·8	16·9
13	N_2 P K	19·7	13·4	17·0
14	N_2 P Mg	19·9	10·3	16·6
15	N_2†P K Na Mg	19·9	11·5	15·9
16	N_2*P K Na Mg	21·1[1]	13·7	20·2
17/18	N_2	19·5	11·0	18·8
17/18	P K Na Mg	9·3	7·5	8·0
19	R	15·7[2]	9·2	15·8
	Mean[3]	16·8	10·5	15·5
Effects:				
Linear N	from plots 5, 6, 7, 8	+4·3	+4·0	+3·1
Quadratic N	from plots 5, 6, 7, 8	−0·9	−0·2	0·0
PKNaMg (3, 5, 7, 10)		+3·9	+3·9	+2·3
FYM minus N_2PKNaMg (2B, 7)		+0·6	+2·8	+2·0
P (10,11)		+2·6	+0·2	−0·5
K (11, 13)		+3·5	+5·7	+2·2
Na (11, 12)		+3·3	+3·1	+2·1
Mg (11, 14)		+3·6	+2·6	+1·8
N*–N (6, 7, 9, 16)		+2·3[1]	+1·7	+1·6
Linear N*	from plots 5, 9, 16	+6·2[1]	+4·4	+5·4
Quadratic N*	from plots 5, 9, 16	−3·0[1]	−1·0	+0·5
N_2PKNaMg minus R (7, 19)		+2·6[2]	+4·2	+2·2
R minus N_2 (10, 19)		+6·0[2]	+1·6	+0·5

[1] 1885–1891.
[2] 1879–1881 the years 1917–1920 when no rape cake was applied were omitted.
[3] Mean excluding plots 9, 16, 19.
N Nitrogen as ammonium salts.
N* Nitrogen as sodium nitrate.
N† All nitrogen as ammonium sulphate in autumn.

On every plot the yield declined from 1852–61 to 1922–25. Yields in the period 1935–64 were mostly about the same as in 1852–61. The lower part of the table presents some comparisons between plots. The regressions of these differences on time, with two exceptions, are not greater than could be expected by chance once in 20 times.

It should be noted that the tests of significance applied to these comparisons are not independent; also, because yields declined between 1852

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TABLE 3·16

Broadbalk, wheat: grain yields, ten-year means, 1852–1967

Total grain, cwt/acre

Plot No.	Treatment	Continuous wheat 1852–61	1862–71	1872–81	1882–91	1892–1901	1902–11	1912–21	1922–25	Transition 1926–34	Fallow cycle 1935–44	1945–54	1955–64	1965–67
2A	FYM[1]	—	—	—	15·2[2]	19·2	19·2	14·8	11·7	15·1	18·4	22·2	23·3	27·1
2B	FYM	19·2	21·3	16·3	21·2	22·7	20·9	16·7	13·1	16·4	20·8	23·6	23·7	27·0
3	None	8·9	8·2	5·7	6·9	7·1	6·4	5·3	3·1	8·1	10·4	10·8	12·6	13·0
5	P K Na Mg	10·3	8·8	6·7	7·7	8·6	8·0	6·1	3·8	8·5	12·0	12·5	13·9	15·5
6	N_1 P K Na Mg	15·2	14·6	10·7	13·7	13·3	12·6	9·7	6·3	12·5	15·2	15·4	17·0	17·5
7	N_2 P K Na Mg	19·3	20·6	15·3	19·6	18·3	18·2	14·2	12·0	16·6	19·4	19·2	20·6	22·2
8	N_3 P K Na Mg	20·1	23·3	17·8	21·6	22·2	22·0	16·5	12·9	17·4	20·8	22·7	22·7	26·6
9	N_1*P K Na Mg	—	—	—	16·9[2]	15·4	16·7	12·5	8·5	14·6	16·8	16·4	17·9	20·4
10	N_2	13·0	14·6	9·6	10·8	10·5	11·1	8·7	5·7	15·1	16·1	16·5	17·2	18·3
11	N_2 P	15·7	16·0	12·2	12·8	11·2	12·0	9·1	5·9	14·8	15·4	16·0	17·0	19·2
12	N_2 P Na	18·6	19·6	14·1	16·8	15·2	16·4	12·2	7·5	16·3	17·8	18·1	17·6	20·0
13	N_2 P K	18·6	20·0	15·1	18·3	16·8	18·9	13·5	10·5	15·9	18·5	18·8	18·9	20·6
14	N_2 P Mg	18·7	19·8	14·7	17·4	14·2	15·1	11·5	8·0	16·2	18·0	18·8	17·5	20·5
15	N_2†P K Na Mg	18·4	19·6	15·0	17·9	15·5	17·9	11·8	8·2	14·9	17·7	17·4	18·0	16·7
16	N_2*P K Na Mg	—	—	—	20·6[2]	18·5	19·7	15·0	12·7	16·9	21·1	21·6	22·1	26·2
17/18	N_2	17·8	17·9	14·4	18·4	16·8	17·9	12·3	8·7	15·1	19·0	19·0	20·2	20·9
17/18	P K Na Mg	10·4	9·6	6·5	7·7	9·3	8·4	6·3	5·2	8·6	10·9	10·8	10·8	12·5
19	R	—	—	12·4[3]	15·7	15·4	15·2	10·1[4]	7·0	14·7	17·9	17·3	17·0	18·8
	Mean[5]	16·0	16·7	12·4	16·3	14·4	14·7	11·0	7·9	14·0	16·6	17·1	17·7	19·3

Notes: [1] FYM since 1885. [2] 7 years (1885–91). [3] 3 years (1979–81). [4] 6 years excluding 1917–20 when no rape cake was obtainable.
[5] Of all treatments started in 1852.

N Nitrogen as ammonium salts. N* Nitrogen as sodium nitrate. N† All nitrogen as ammonium sulphate in autumn.

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TABLE 3·17

Broadbalk wheat: straw yields, ten-year means, 1852–1967

Total straw, cwt/acre

Plot	Treatment	Continuous wheat 1852–61	1862–71	1872–81	1882–91	1892–1901	1902–11	1912–21	1922–25	Transition 1926–34	Fallow cycle 1935–44	1945–54	1955–64	1965–67
2A	FYM[1]	—	—	—	25·1[2]	33·5	38·7	26·8	23·9	41·0	45·6	45·4	34·3	38·8
2B	FYM	33·9	34·0	28·0	34·8	38·7	40·9	31·7	28·4	47·0	49·0	49·7	36·9	40·2
3	None	15·2	11·5	8·5	8·5	9·1	9·6	7·3	5·2	14·0	17·6	18·6	15·0	15·1
5	P K Na Mg	17·0	12·8	9·7	9·9	11·5	12·4	8·7	5·8	15·9	21·7	23·9	20·2	18·8
6	N_1 P K Na Mg	26·3	22·8	17·7	20·5	20·0	22·4	15·6	10·6	26·0	29·5	30·6	25·3	23·5
7	N_2 P K Na Mg	36·4	34·3	28·7	34·1	31·0	35·5	25·7	24·8	41·6	41·3	39·0	32·1	32·9
8	N_3 P K Na Mg	40·4	42·2	36·6	42·5	41·5	45·6	33·4	31·4	51·8	51·8	48·2	36·2	39·3
9	N_1*P K Na Mg	—	—	—	28·7[2]	26·1	30·5	21·7	17·6	33·6	33·2	32·0	26·4	29·1
10	N_2	24·6	21·9	15·2	15·8	16·1	18·0	14·7	13·0	30·3	29·5	30·0	20·7	21·7
11	N_2 P	28·2	24·5	21·3	20·8	18·7	21·8	17·1	16·9	33·0	29·9	30·0	21·9	23·7
12	N_2 P Na	34·2	30·5	25·0	27·3	23·9	28·7	21·6	18·8	36·7	34·1	33·4	24·0	25·2
13	N_2 P K	34·3	33·3	27·6	31·9	28·5	35·9	26·2	23·1	40·0	39·2	37·2	29·6	30·8
14	N_2 P Mg	35·0	30·7	26·3	28·6	23·3	26·3	21·0	19·9	37·2	35·6	34·4	23·1	26·9
15	N_2†P K Na Mg	34·1	32·2	25·3	30·1	26·4	32·0	21·3	18·1	33·4	33·8	34·2	27·4	23·8
16	N_2*P K Na Mg	—	—	—	40·1[2]	33·1	41·2	30·5	28·7	43·0	45·2	42·8	33·4	39·7
17/18	N_2	33·2	29·2	26·0	30·6	27·4	32·1	21·9	18·0	36·3	37·3	35·0	29·4	29·8
17/18	P K Na Mg	17·7	14·5	10·0	10·5	12·1	13·4	8·6	8·9	17·1	19·9	20·0	16·6	15·2
19	R	—	—	19·1[3]	25·5	25·4	27·4	15·3[4]	17·1	33·9	32·0	32·4	25·2	25·8
	Mean[5]	29·3	26·7	21·9	24·7	23·4	26·8	19·6	17·4	32·9	33·6	33·2	25·6	26·2

[1] FYM since 1885. [2] 7 years (1885–91). [3] 3 years (1879–81). [4] 6 years excluding 1917–20 when no rape cake was obtainable.
[5] Of all treatments started in 1852.

N Nitrogen as ammonium salts. N* Nitrogen as sodium nitrate. N† All nitrogen as ammonium sulphate in autumn.

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and 1925, it might be expected that the effects of some treatments would decline roughly in proportion. A few changes, nevertheless, are worth mentioning.

The effect of superphosphate (plot 11 *minus* plot 10) declined significantly (probability less than 0·01) in the period of continuous wheat. It was between 2 and 3 cwt in the early years but negligible in the later years and in the fallow-cycle. This decline in the effect of P applied cumulatively is difficult to explain but it must be remembered that both the plots involved have received no K during the experiment; in this respect winter wheat on Broadbalk contrasts with spring barley on Hoosfield Permanent Barley, where yields have been greatly increased by P throughout the period of the experiment. (See *Rothamsted Report for 1966*, 320–338).

TABLE 3·18

Broadbalk wheat: long period mean yields of grain and straw: continuous wheat 1852–1925, fallowing system 1935–64; whole period 1852–67

Total grain and total straw, cwt/acre

Plot No.	Treatment	Grain 1852–1925	Grain 1935–64	Grain 1852–1967	Straw 1852–1925	Straw 1935–64	Straw 1852–1967
2A	FYM[1]	16·7[2]	21·3	17·3	30·8[2]	41·8	34·1
2B	FYM	19·4	22·7	19·5	34·2	45·2	37·1
3	none	6·7	11·3	7·7	9·8	17·1	11·2
5	P K Na Mg	7·8	12·8	9·0	11·5	21·9	14·0
6	N_1 P K Na Mg	12·5	15·9	13·0	20·3	28·5	22·1
7	N_2 P K Na Mg	17·6	19·7	17·7	32·1	37·5	33·2
8	N_3 P K Na Mg	20·1	22·1	20·1	39·8	45·4	41·5
9	N_1*P K Na Mg	13·9[2]	17·0	14·7	24·6[2]	30·5	27·2
10	N_2	10·9	16·6	12·6	17·8	26·7	20·4
11	N_2 P	12·3	16·1	13·3	21·4	27·3	23·2
12	N_2 P Na	15·7	17·8	16·2	26·8	30·5	27·7
13	N_2 P K	17·0	18·7	17·0	30·6	35·3	31·6
14	N_2 P Mg	15·5	18·0	16·0	26·8	31·1	27·9
15	N_2†P K Na Mg	16·1	17·7	16·0	28·2	31·8	28·7
16	N_2*P K Na Mg	17·8[2]	21·6	18·9	35·2[2]	40·5	36·7
17/18	N_2	16·1	19·4	16·8	28·1	33·9	29·7
17/18	P K Na Mg	8·1	10·8	8·2	12·3	18·8	13·0
19	R	14·7[3]	17·4	15·2	23·7[3]	29·9	25·5

Notes: [1] Since 1885. [2] 1885–1925. [3] 1879–1925; omitting 1917–20.

N Nitrogen as ammonium salts.
N* Nitrogen as sodium nitrate.
N† All nitrogen as ammonium sulphate in autumn.

The comparison between rape cake (plot 19) and ammonium sulphate supplying about the same amount of N (plot 10) shows a significant (probability less than 0·01) slow change and again the small difference in the late period of continuous wheat is confirmed in the fallow-cycle period.

The decline in the quadratic component of the effect of ammonium sulphate (one quarter of the difference plot 5 plus plot 8 minus plot 6 minus plot 7) approaches significance, and is partially confirmed in the fallow period. This indicates that the difference in yield between plot 8 (129 lb N) and plot 7 (86 lb N) has increased relative to the difference

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between plot 6 (43 lb N) and plot 5 (no N), but this change may be attributed to the change in the method of applying ammonium sulphate (see Table 3·6).

TABLE 3·19

Broadbalk wheat: yields in the first, second, third and fourth years after bare fallow

Mean of six cycles, 1935–64, total grain and total straw (cwt/acre)

		Grain				Straw			
Years after fallow		1	2	3	4	1	2	3	4
Plot No.	Treatment								
2A	FYM[1]	25·8	21·5	20·0	17·9	52·0	40·3	38·2	36·6
2B	FYM	26·4	23·3	21·2	20·0	53·2	44·5	41·8	41·2
3	none	16·3	9·8	9·5	9·5	25·7	14·4	14·0	14·2
5	P K Na Mg	18·7	10·8	10·2	11·4	32·2	18·2	17·8	19·5
6	N_1 P K Na Mg	21·6	14·7	13·0	14·2	39·4	25·3	23·6	25·7
7	N_2 P K Na Mg	23·4	19·8	17·7	18·0	45·7	37·0	33·1	34·1
8	N_3 P K Na Mg	24·5	22·7	20·5	20·6	48·9	46·5	43·4	42·9
9	N_1*P K Na Mg	21·4	16·6	14·9	15·3	39·5	29·0	26·3	27·4
10	N_2	16·7	18·8	15·5	15·3	28·7	29·2	24·7	24·2
11	N_2 P	17·1	17·9	14·7	14·8	30·1	29·2	25·0	24·8
12	N_2 P Na	18·7	19·0	16·6	16·9	34·7	31·8	27·5	28·0
13	N_2 P K	23·2	18·3	16·4	17·0	44·3	34·6	30·6	31·8
14	N_2 P Mg	20·0	18·9	16·7	16·6	36·3	32·2	27·8	28·0
15	N_2†P K Na Mg	23·0	16·4	15·4	15·9	41·8	29·1	27·1	29·3
16	N_2*P K Na Mg	24·3	21·7	20·2	20·2	47·8	39·8	37·4	36·8
17/18	N_2	22·8	18·1	17·9	18·8	40·9	31·2	31·5	31·9
17/18	P K Na Mg	17·8	9·4	7·9	8·0	31·7	16·0	13·7	13·9
19	R	21·9	17·0	14·9	15·8	38·7	28·9	25·4	26·4
	Mean	21·3	17·5	15·7	15·9	39·5	31·0	28·3	28·7

[1] Since 1885.

N Nitrogen as ammonium salts.
N* Nitrogen as sodium nitrate.
N† All nitrogen as ammonium sulphate in autumn.

Investigations into the Effects of Weather on Yields

By F. Yates

The records of Broadbalk field, and of the other classical fields at Rothamsted, seem at first sight to be ideal for the study of the effects of meteorological factors on the yield of crops grown under uniform conditions, and of variations of these effects with contrasting fertiliser treatments.

Fisher turned his attention to this problem early in his career at Rothamsted, when he made an extensive investigation of the effects of rainfall (1924). It is, of course, to be expected that rain falling at different times of the year may well have very different effects on the yield. The arbitrary division of the rainfall record into periods, each of which is used as an independent variate in a multiple regression on yield is a crude method of allowing for this, but is open to the objection that the effect of rain falling on say 31 March, can only be trivially different from that falling on 1 April. To overcome this defect, Fisher fitted a smooth

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two principal diseases, virus yellows and blight, and used average yields over a whole district. One motive for the meteorological investigations on Broadbalk, was the belief that, because the field was growing wheat year after year under conditions that were kept as uniform as possible, much of the variation in yield must depend on relatively simple meteorological differences. The secondary effects, e.g. cultivation under difficult conditions, or disease dependent on many factors other than the weather of the current crop year, almost certainly account for much of the variation, and some of this at least will be averaged out when yields over a whole district are taken.

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