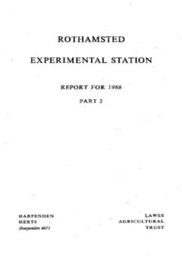
This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/).

Thank you for using eradoc, a platform to publish electronic copies of the Rothamsted Documents. Your requested document has been scanned from original documents. If you find this document is not readible, or you suspect there are some problems, please let us know and we will correct that.

Rothamsted Experimental Station Report for 1968 - Part 2


ROTHAMSTED
EXPERIMENTAL STATION
REPORT FOR 1968
PART 2
HARPENDEN
HERTS
LAWES
AGRICULTURAL
TRUST

Full Table of Content

2. Historical Introduction

A. E. Johnston and H. V. Garner

A. E. Johnston and H. V. Garner (1969) *2. Historical Introduction ;* Rothamsted Experimental Station Report For 1968 - Part 2, pp 12 - 25 **- DOI: https://doi.org/10.23637/ERADOC-1-2**

This work is licensed under a Creative Commons Attribution 4.0 International License.

2. HISTORICAL INTRODUCTION

A. E. JOHNSTON and H. V. GARNER

The early 1840s, when Lawes started his experiments with manures and crops, were the beginning of a period of considerable change in European agriculture which, for many centuries, had produced cereal grains for human consumption, initially by shifting cultivation, then by a cycle of cereal cropping and fallow. It had long been known that some crop other than a cereal could replace the fallow and that when grown after peas, beans or vetches, cereals did as well as after a fallow and that after clover or trefoil they yielded better. During the early 18th century root crops were introduced and farmers began to grow crops in rotation. The best known rotation, the Norfolk four-course, was a root crop, cereal, legume, cereal. There is some evidence that at Rothamsted a five-course rotation was practised in the 1840s with a second cereal taken in the fifth year. Only the root crop was manured, usually with farmyard manure (FYM) made by animals fed on the produce from the arable crops and permanent meadows of the farm; only animal products and cereal grains were sold off the farm. It was soon realised that this system of farming maintained or increased yields of cereals and attempts were made to explain its greater success than monoculture. However, too little was known about nutrition, physiology and pathology to provide explanations.

Early theories about plant nutrition postulated that plants derived all their substance from one source or 'principle' of vegetation by transformation of elements; the two most favoured principles were water and humus. Even as late as 1796 it was still thought that plants could generate alkalies and silica. Between 1750 and 1800 the compositions of both the atmosphere and water were established, and the fact that plants derived their carbon and oxygen from the atmosphere and hydrogen and oxygen from water taken up by the roots. The role of light in photosynthesis was shown, and that plants respired and evolved carbon dioxide in the dark.

In 1804, de Saussure published analyses of the ash of many plants and concluded that these incombustible or mineral constituents were derived from the soil. He further concluded that plants obtained their nitrogen from nitrogenous compounds in the soil and from the small amount of ammonia carried into the soil from the atmosphere by rain. In 1834 Boussingault, a chemist, became joint owner of an estate in Alsace; his partner was both a chemical manufacturer and a farmer who recorded the weights of manure used and crops and cattle produced on his farm. Boussingault extended these simple measurements into field experiments and within the considerable limitations of the analytical procedures at his disposal had, before 1840, produced a nutrient balance sheet for five different rotations of crops. He concluded that:

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

1. The best rotations were those that accumulated most nitrogen and carbon because crops removed more of these two elements than were supplied in manure.
2. Some plants, especially legumes, not only accumulated more nitrogen than others in their produce but also left some in the soil.
3. The value of a manure was to a great extent measurable by the nitrogen it contained.

The British Association for the Advancement of Science asked Liebig to prepare a report on agriculture and chemistry and this was first published in 1840 under the title, 'Organic Chemistry in its Applications to Agriculture and Physiology'. In this he discussed the work of others, often with considerable scorn and ridicule, and his own. Written more clearly and with fewer contradictions than was usual at this period, it stimulated much further work. Liebig stated the plant's sources of carbon, hydrogen and oxygen; he agreed with Boussingault about the importance and sources of nitrogen, especially the ammonium-N in manures and, using de Saussure's results, also stressed the importance of the inorganic or mineral constituents taken up from the soil. He was aware of the insolubility of many soil minerals and considered the function of humus was to provide carbon dioxide which reacted with water to give carbonic acid able to dissolve compounds containing alkalies. To maintain soil fertility he considered it necessary to return to the soil as manure the mineral constituents and the nitrogen removed in the crop, and he extended this thesis to suggest that suitable manures could be developed for each crop from precise plant analyses.

While at Oxford, Lawes attended lectures given by Professor Daubeny and must also have seen his experiments with plants done in pots and on small plots in the Botanic Garden. These plots were designed to show whether soil exhaustion or injurious excretions from roots were responsible for a crop grown in monoculture yielding less than when grown in rotation. Returning to Rothamsted, Lawes had tested, before 1840, how various mineral and other substances added to Rothamsted soil in pots and small plots affected the growth of different crops. He was impressed by the effects of 'earthy phosphates decomposed by sulphuric acid', which later led to his patent for superphosphate manufacture and the start of his manure business. The results of these early experiments appeared in the *Gardener's Chronicle*, but it was not until 1847 that Lawes sent his first paper to the Royal Agricultural Society of England (R.A.S.E.) for publication in their Journal, which had first appeared in 1840.

During the early 1840s both these journals were publishing the results of experiments by farmers with various manures, dissolved bones, guano, rape cake, saltpetre and FYM. Usually only two or three materials were tested in each experiment using single plots, and the results were inconsistent even if not contradictory. At this time, Henslow at Cambridge and Johnston at Durham were campaigning for more carefully conducted and systematic experiments. In his published work between 1841 and 1849 Johnston advocated testing the effects of single substances and estimating error from natural causes by using two untreated plots on each experi-

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

mental site. He also suggested using various amounts of fertilisers and foresaw interactions between individual fertilisers and with variety and soil type. Most important, he appreciated that badly made experiments can lead to the spread of erroneous deduction and opinion and financial loss (Johnston, 1842, 1849). In 1841, Daubeny, invited to lecture to the R.A.S.E., pleaded eloquently for organised experiments in agriculture in England, 'the only civilised country in Europe without a public establishment for such experiments' (Daubeny, 1842). He saw the need for experimental farms for research and model or example farms for demonstration. He thought that the running of an experimental farm could well be one of the objects of the R.A.S.E. rather than any one person, for he noted 'the difficulty of meeting in any one individual with that union of science, perseverance, capital and devotion both of time and money which such experiments involve'. However, it was one of Daubeny's former pupils who proved to be such an individual, for, in addition to the other qualities enumerated, Lawes during the 1840s spent more than £1000 per year on his field experiments alone.

Lawes defined agriculture as 'the production of food for man or other animals on a space of ground incapable of supporting them in its natural state', and from this definition he saw the great problem to be, 'What substances is it necessary to supply to the soil in order to maintain a remunerative fertility?' (Lawes, 1847). To answer this question he had decided by 1843 'to make experiments at once more systematic and on a larger scale, on some of the most important crops of our rotations' (Lawes & Gilbert, 1864). Whereas Boussingault had studied the total manuring of a rotation of crops, Lawes made an important decision when he decided to study the manuring of the individual crops commonly grown in rotation, considering that 'comparative results obtained by growing crops year after year on the same land without manure and with different manurial constituents singly and in admixture are far better calculated to indicate in what constituent or constituents the soil is relatively deficient so far as the available supply for the crop to be grown is concerned . . .' (Lawes & Gilbert, 1873). In the spring of 1843 turnips were sown on Barnfield, which was to be the field for root experiments. This was started just before Lawes appointed Gilbert, as chemist, in June. In the autumn of 1843 the first experimental wheat crop was sown on Broadbalk. This 14-acre field was chosen because it 'had grown turnips, barley, peas, wheat and oats since the application of manure, and would, therefore, according to the ordinary rules of practice, be considered so far exhausted as to require to be remanured before growing another crop' (Lawes & Gilbert, 1864). It was therefore a suitable site for a manuring experiment.

A second important decision made by Lawes when he started the experiments on Barnfield and Broadbalk was to have large plots. Their large size has been of supreme importance, not only as an acceptable demonstration to farmers in the early years but also because it allowed the plots to be sub-divided in the 1920s and 1960s and increased their usefulness. In both experiments each plot was as long as the field and the width, 19·7 links on Barnfield, 18·7 links on Broadbalk, was the ploughman's land, the distance between the water furrows when a field was laid up in ridges and furrows.

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

There were 23 plots each about one-third of an acre on Barnfield and each received a different manurial treatment. On Broadbalk the plots were either one or two lands wide, that is, about either one-third or two-thirds acre. Each plot received a different manurial treatment. In the second year on Broadbalk the same plots were used, but for the third crop the 'double land' plots were halved (half-plot 'a' on the north and 'b' on the south side), and for the next few years many of the halves received different manures. From 1852, however, the halves, other than 9a, 9b, 15a, 15b, received the same manures but were harvested separately for yield until 1893. The paths that now separate the plots were not made until 1894, when the 'a' and 'b' halves of each plot were 'thrown together' and harvested as one unit. At this time a path was made separating the plots into west and east halves. This arrangement of the plots continued until 1926 when each was divided into five sections, section I at the western, upper end. On the five sections a cycle of 4 years cropping and 1 year fallow was introduced, the fallow was cultivated to control weeds. Section I was halved into 'A' and 'B' subsections in autumn 1955, before it was due for fallow in 1956; section IA was cropped in 1956, section IB was fallowed. Thus section IA was last fallowed in 1951 and has grown wheat continuously since, with weeds controlled by herbicides. Section V was divided in autumn 1954 for a test of liming, section VB received 5 tons $CaCO_3$/acre. This test was discontinued in autumn 1962; section VB was cropped in 1963 instead of fallowed and continuous wheat was reintroduced to this part of the field. Section VA received a heavy dressing of chalk in autumn 1963 (for details see Table 2·2).

On Broadbalk the simple arrangement of plots and treatments has remained basically unchanged, whereas Lawes and Gilbert modified and improved the design used on Barnfield. In 1845 the PKNaMg treatments on Barnfield were restricted to strips, mostly made by combining three of the original plots, which were crossed at right angles by various nitrogen treatments. In 1852, when the barley experiment on Hoosfield was set out, the PKNaMg treatments were again in strips crossed at right angles by the nitrogen treatments, but a small group of plots, 'the gauge series', including an FYM and second unmanured plot, were set out to one side of the experiment. In 1856 further modifications were made on Barnfield when FYM and FYM + P (later PK) were introduced as main strip treatments crossed by the nitrogen treatments, so that all combinations of unmanured, fertiliser, FYM and FYM + fertiliser treatments were tested.

A third important decision Lawes made in 1843 was to test several fertilisers singly and in combination in each experiment. On Barnfield he used those he had found improved growth in pots and small plots and these were consistent with Liebig's early views on the relative importance of supplying mineral constituents and nitrogen. The early growth of turnips was greatly increased by phosphatic manures, FYM, rape cake and guano. There was little effect from nitrogen, probably because the manures were drilled with the seed and the inorganic nitrogenous manures greatly decreased plant numbers. Having observed these effects on the growing turnips, Lawes and Gilbert decided the manurial treatments to be used on Broadbalk. There was an unmanured and an FYM plot, whose yields were

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

the standards by which the effects of the other treatments were to be judged. Of the remaining 18 plots all had some form of mineral manure, 3 had rape cake, but only 5 had inorganic N-fertiliser and then in small amounts. K, Na, Mg were tested as phosphates or silicates, because the chemists of this period, balancing out the acids and bases found by analysis of the plant ash, thought that these cations were united with phosphate.

The inorganic or mineral manures by themselves produced little or no increase in the yield of the first winter wheat crop harvested in 1844, but ammonium sulphate supplying only about 12 lb N/acre produced a much larger crop. This result did not support Liebig's latest views put forward in the 3rd edition of his book, published in August 1843, which omitted all reference to the need to supply nitrogen in manures and maintained that the total nitrogen requirement of a crop was met by the ammonia in the atmosphere. So in the second year Lawes and Gilbert, quick to appreciate the significance of the first year's results, applied inorganic N to 14 plots and tested 20, 40, 60 lb N/acre. An increase in yield was obtained for each increment of inorganic-N applied as fertiliser; the long battle with Liebig on the source from which plants derive their nitrogen started. During the next few years the treatments on many plots varied from year to year (see Table 2·1), but always to test some point, the source of a nutrient, whether a fresh supply each year was essential, whether there was any residual value.

In 1852 Lawes and Gilbert made a fourth important decision when they resolved to keep the manuring on each plot constant and the details of manuring and cultivations from that year are shown in Tables 2·1 and 2·2, together with a plan of the plots. In the early years details of cultivations and notes about the crop were written by hand in note books. There is some evidence that about 1860 these notes were copied into a large white-bound book and from then on fact and comment were entered each year. Lawes and Gilbert kept one such book for each experiment and these records are now referred to as the 'White Books.'

In addition to the unmanured and FYM plots, there were two main groups of treatments:

1. Amounts and forms of nitrogen, 0, 43, 86, 129 lb N/acre/year as ammonium-N (Lawes and Gilbert originally included 172 lb nitrogen also) and nitrate-N at 43 and 86 lb nitrogen were tested in the presence of phosphorus, potassium, sodium and magnesium.
2. The effects of phosphorus, potassium, sodium and magnesium in the presence of nitrogen were tested.

One-year residual effects of N and PKNaMg were measured, and the effect of rape cake applied each year.

The amounts of N, P and K used each year were generous and had no relation to the amount taken up by the crop. For this Lawes and Gilbert were often criticised, but they replied to their critics in their barley paper published in 1873 as follows '. . . with the existing knowledge at the time of the arrangement of the experiments—nay, even with the present knowledge, or rather ignorance—of the reactions of the different manurial substances within the soil, of the consequent distribution and state of combination within it of the constituents they supply, and of how far,

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

accordingly, they are available for the crop to be grown, it would be the merest pedantry to apply only so much of each constituent as had been, or was expected to be, removed in the crop. We have, indeed, followed the plan supposed by our critics, in isolated cases, with the view of testing the validity of the assumptions upon which it is founded, and the result has been most signal failure, so far as the amount of the resulting crop is concerned.' (Lawes & Gilbert, 1873.)

References

BOUSSINGAULT, J. B. (1845) *Rural economy, in its relations with chemistry, physics and meteorology*. London: H. Bailliere, Publisher. 690 pp. (English translation with a summary of Boussingault's work up to that time).

DAUBENY, C. (1842) Lecture on the application of science to agriculture delivered before the members of the Royal Agricultural Society of England, December 1841. *Jl R. agric. Soc.* 3, 136–160.

GREY, E. (1922) *Rothamsted Experimental Station; reminiscences, tales and anecdotes of the laboratories, staff and experimental fields, 1872–1922*. London: The Dangerfield Printing Co. Ltd., 155 pp.

JOHNSTON, J. F. W. (1842) *Lectures on agricultural chemistry and geology*. London: W. Blackwood & Sons, p. 1027.

JOHNSTON, J. F. W. (1849) *Experimental agriculture*. London: W. Blackwood & Sons, 265 pp.

LAWES, J. B. (1847) On agricultural chemistry. *Jl R. agric. Soc.* **8**, 226–260.

LAWES, J. B. & GILBERT, J. H. (1864) Report of experiments on the growth of wheat for twenty years in succession on the same land. *Jl R. agric. Soc.* **25**, 93–185, 449–501.

LAWES, J. B. & GILBERT, J. H. (1873) Report of experiments on the growth of barley for twenty years in succession on the same land. *Jl R. agric. Soc.* Ser. 2, **9**, 89–186, 275–374.

LIEBIG, J. (1840) *Organic chemistry in its applications to agriculture and physiology*. London: Taylor and Walton. 387 pp.

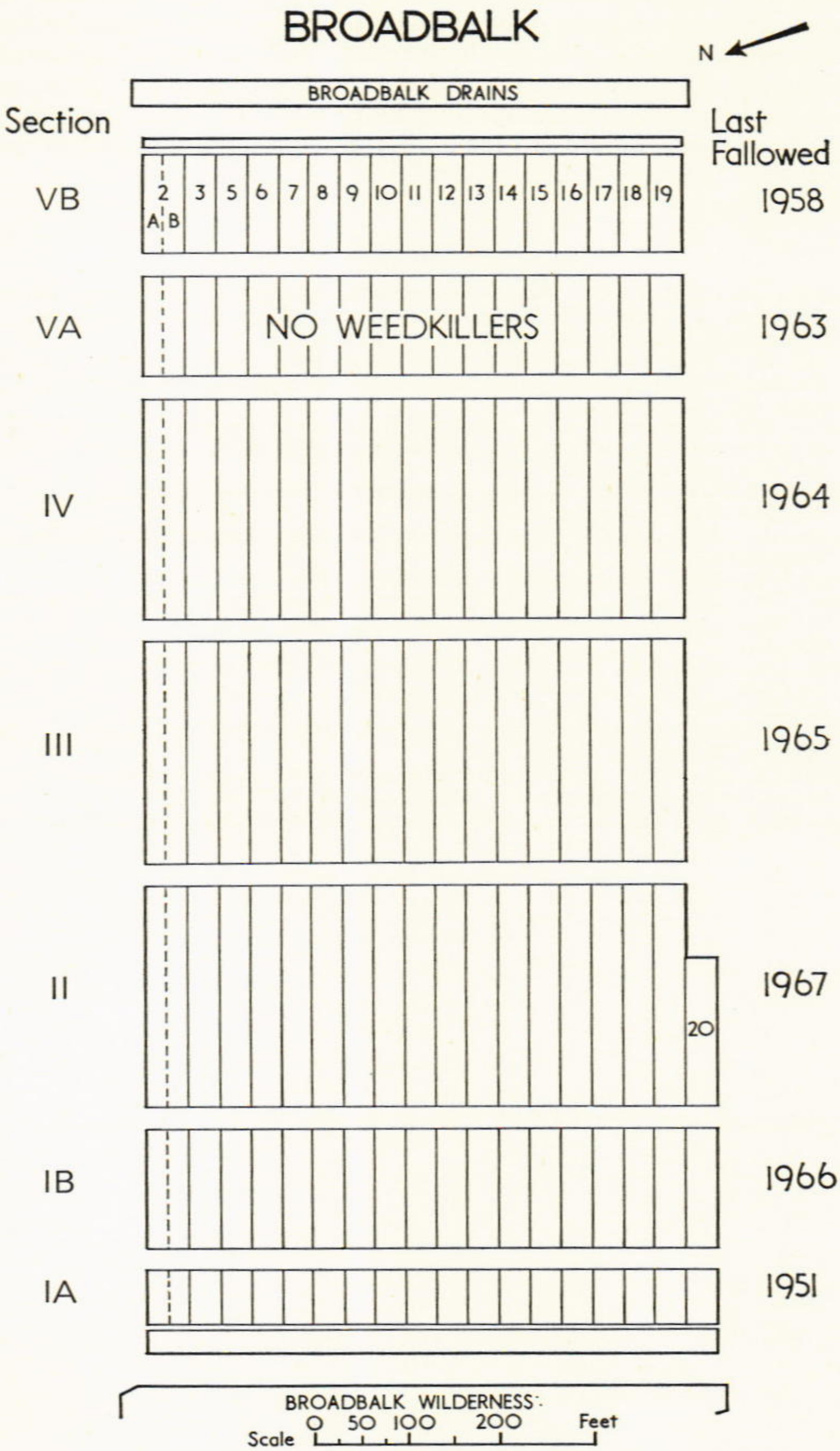
MOFFATT, J. R. (1939) Agricultural methods adopted in the Rothamsted Classical and modern field experiments. *Emp. J. exp. Agric.* **7**, 251–260.

SAUSSURE, T. de, (1804) *Recherches chimiques sur la vegétation*. Paris. 327pp.

For plan see over. For Table 2.1 see p. 19 and Table 2.2 see p. 21.

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/).



https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

TABLE 2·1

MANURIAL HISTORY OF THE BROADBALK WINTER WHEAT PLOTS 1852–1967

(For treatments 1844–51 see over)

Plot		Treatment from 1852
2A	FYM since 1885	In 1885 this new plot was made from two half plots, the one on the south had been unmanured since 1844 and the other was half of the original plot 1 which had KNaMg between 1844 and 1883 and was fallowed in 1884.
2B	FYM	
3	None	Originally 2 half plots 3 and 4 3, unmanured 4, 1844–51, NP‡; since 1852 unmanured.
5	P K Na Mg	
6	N_1 P K Na Mg	
7	N_2 P K Na Mg	
8	N_3 P K Na Mg	
9	N_1*P K Na Mg	Since 1894; previously 9a 1852–54 N_1*, 1855–84 N_2*P K Na Mg, 1885–93 N_1*P K Na Mg. 9b 1852–54 N_2*, 1855–84 N_2*, 1885–93 N_1*.
10	N_2	
11	N_2 P	
12	N_2 P Na§	
13	N_2 P K	
14	N_2 P Mg§	
15	N_2†P K Na Mg	Since 1873 all N in autumn. See note in Table 2·2 about times N was applied. 15a 1852–72 N_2 P K Na Mg‡ 15b 1852–72 $N_{1\cdot5}$ P K Na Mg‡ + 500 lb rape cake
16	N_2*P K Na Mg	Since 1884; previously 1852–64 N_4PKNaMg, 1865–83 unmanured.
17	N_2	applied in alternate years: Plot 17, N in even years, Plot 18, N in odd years
18	P K Na Mg	
19	Castor meal (R)	The size of the present plot only since 1904. The original plot 19 was a half width plot, 1852–78 $N_{1\cdot5}$ + P‡ + 500 lb rape cake, 1879–1904, rape cake. In 1894 the original plot 20 unmanured, a half width plot 500 lks long at the west end of the plots was taken into plot 19. In 1904 the total length of the plot was made full width by taking in land from the headland.
20	N_2 K Na Mg	Since 1906. The original plot 20 was unmanured after 1846 and was taken in to plot 19 in 1894. A new plot 20, width as plots 3–18 was made on ground previously known as Knott Wood Butts and unmanured. 1894–1905 unmanured.

N Nitrogen as ammonium salts.
N* Nitrogen as sodium nitrate.
N† All nitrogen as ammonium sulphate in autumn. See note Table 2·2.
‡ P made with hydrochloric acid, all N as ammonium sulphate.
§ See Table 2·2 for amount, Na and Mg are applied in chemically equivalent amounts.

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

TABLE 2·1—continued

MANURING 1844–51

The manuring was such as to supply the known constituents of the ash of wheat grain and straw in various forms. These were the 'inorganic' or 'mineral' manures:

Potassium as pearl ash (partly purified potassium carbonate derived from plant ash) potassium sulphate and potassium silicate;
Sodium as soda-ash and sodium sulphate;
Calcium as calcium sulphate and calcium phosphate;
Magnesium as magnesium limestone and magnesium sulphate;
Phosphorus, in bone ash made soluble by pretreatment with sulphuric or hydrochloric acid (a residue of bones treated with HCl was apparently a waste product from glue manufacture).
Sulphate in most of the above materials;
Chlorine as sodium chloride;
Silica in the potassium silicate.

Nitrogen was applied as ammonium sulphate, chloride or carbonate or in sodium nitrate, in FYM and rape cake.

Non-nitrogenous organic matter, rice, tapioca and straw, which was thought to yield by decomposition carbonic acid to act on insoluble soil constituents, was also tested.

In the first years Lawes and Gilbert also tested the ash of FYM and Liebig's patent wheat manure, which supplied the amount of minerals removed by an average crop; both were without effect.

Plot treatments, especially during the first three years, were arranged to answer specific points, and to determine the effect of individual nutrients and their residual effects. Lawes and Gilbert soon realised their mistake, made, 'not with that full appreciation of the desirableness of maintaining exactly, and easily comparable relations between one plot and another for a long series of consecutive seasons'. After the fourth year the treatments on each plot became much more uniform and in the ninth year, 1852, 'it was definitely arranged to supply, throughout the field, the same manure year after year, on the same plot, for many successive seasons' (Lawes & Gilbert, 1864).

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

TABLE 2·2

DETAILS OF MANURES, DRAINING, CULTIVATIONS AND CROPPING, BROADBALK WINTER WHEAT, 1844–1967

Fertilisers and FYM applied annually in autumn before sowing, except N, see below.

Amounts per acre†

NITROGEN

Ammonium sulphate at 210, 420, 630 lb, (N_1, N_2, N_3) supplying 43, 86, 129 lb N. 172 lb N (N_4) was tested until 1864.

Before 1917 a mixture of equal weights of ammonium sulphate and ammonium chloride was used (except 1887 ammonium sulphate only). In 1901 the mixed salts applied in spring were compared with ammonium bicarbonate on quarter plots in the west half of the experiment. From 1844–51 various amounts of ammonium sulphate, ammonium chloride and the mixed salts were used.

Sodium nitrate at 275, 550 lb from 1885, (N_1*, N_2*) supplying 43 and 86 lb N; previously N_2* only from 1855.

PHOSPHORUS

Superphosphate containing 29–30 lb P, 66–69 lb P_2O_5 (366 lb 18·5% P_2O_5 superphosphate).

Before 1889 superphosphate was made on the Farm from calcined bone dust and acid. From 1844 to 1847 various proportions of bone dust and sulphuric acid or hydrochloric acid were used. From 1848 to 1888 200 lb calcined bone dust was treated with 150 lb sulphuric acid (sp. gr. 1·7). From 1889 superphosphate was supplied ready made and the weight adjusted to give the same amount of phosphorus as in the period 1848–88. 1898–1902 basic slag (400 lb) used instead of superphosphate.

Phosphorus dressings omitted 1915.

POTASSIUM

Potassium sulphate *1852–1858* 300 lb containing 120 lb K (145 lb K_2O)
1859–1967 200 lb containing 80 lb K (96 lb K_2O)

Potassium dressings omitted 1915, 1917, 1918, 1919.

From 1843 to 1851 various weights of pearl ash (45% K) and potassium sulphate were tested.

SODIUM

Sodium sulphate *1852–1858* 200 lb containing 28 lb Na
1859–1967 100 lb containing 14 lb Na

Sodium dressings omitted 1915

exception plot 12 *1852–1858* 550 lb containing 77 lb Na
1859–1967 336½ lb containing 51 lb Na

Sodium dressings omitted 1915, 1917, 1918, 1919.

From 1843 to 1851 various amounts of soda ash (34% Na) and sodium chloride were tested.

MAGNESIUM

Magnesium sulphate *1852–1967* 100 lb containing 10 lb Mg

Magnesium dressings omitted 1915

exception plot 14 *1852–1858* 420 lb containing 42 lb Mg
1859–1967 280 lb containing 28 lb Mg

Magnesium dressings omitted 1915, 1917, 1918, 1919.

From 1843 to 1851 various amounts and forms of magnesium were tested.

† Plot areas. The sizes of the whole plots were decreased in autumn 1893 when the 'a' and 'b' halves of the plots were ploughed together leaving a path on either side of the plot; to maintain the amounts of nutrients per acre the manures applied per plot were correspondingly smaller. Since 1926 the section of plots fallowed each year has been unmanured and since 1954, not limed.

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

TABLE 2·2—continued

SILICATE TEST

1862–1863. A strip 16·5 ft wide at the eastern end of all plots was dressed with a mixture of 200 lb sodium silicate + 200 lb calcium silicate. Another 16·5 ft wide strip received a mixture, at 400 lb per acre, of 8 cwt soluble silica rock, 1 cwt fresh burnt lime and 20 lb common washing soda mixed together with hot water to a thick paste.

1864–1866. 288 lb of the above silicate rock mixture tested on the 'a' halves of plots 5, 6, 7, 8, 9, 16, 18.

1868–1879 on the 'a' halves of plots 5, 6, 7, 8, 11, 12, 13, 14 and of 17 or 18, whichever received PKNaMg, the total straw grown on that plot the previous season was chaffed, spread and ploughed in. The straw was used as a source of silica and continued the tests of silica made in 1862–66.

FARMYARD MANURE

14 tons The analyses Lawes and Gilbert had in the 1840s showed that 14 tons 'average' FYM contained 200 lb total N. In recent years the FYM has been made by fattening bullocks treading straw in covered yards during the winter.

CASTOR MEAL

1852–1878	500 lb rape cake tested with N and P
1879–1882	1700 lb rape cake (probably supplied 86 lb N)
1883–1940	1889 lb rape cake (probably supplied 89 lb N) dressings omitted 1917–20
1941–1954	1889 lb castor bean meal
1955–1967	weight per acre of castor bean meal adjusted for analysis so that total nitrogen applied equalled 86 lb N.

LIMING

For an account of the chalking before the experiment started see Avery and Bullock page 67.

To correct acidity that had developed on parts of some plots, especially at their eastern ends, ground chalk (5 tons $CaCO_3$/acre) was applied to all of section VB in autumn 1954 and to all of section VA and plot 19 section IV in autumn 1963. To prevent further acidity developing, a scheme was introduced whereby chalk was applied annually to the stubble before ploughing, except for the section to be fallowed which also received no fertilisers. The amount was based on the acidifying effect of the ammonium sulphate (100 lb $CaCO_3$ for every 14 lb N as ammonium sulphate) and the castor meal (50 lb $CaCO_3$ for every 14 lb N as castor meal). The first dressing in autumn 1954 was double this amount to assist the recovery of some of the acid plots. A survey of the surface soil pH values in 1967 showed that some small areas required further chalking and various amounts of chalk (23–69 cwt $CaCO_3$) were applied in autumn 1967.

DRAINING

Although Lawes described the soil of Broadbalk as having a good natural drainage, because it was an experiment it was necessary to get on the land for longer periods than under normal agricultural practice and it was decided to improve the drainage. Tile drains were put under the centre furrow separating the 'a' and 'b' halves of each plot (except the present plot 20) in autumn 1849. Plot 2A (FYM since 1885) was drained in autumn 1884 before the first application of FYM was given. Tiles of 'horseshoe and sole' type (2 in. in diameter) were laid between 2 and 2·5 ft deep except under the west side of section III where they were about 3 ft deep. The fall of the drains was given by the general, but not uniform, slope of the field from west to east, about 12 ft on plot 19 and 16 ft on plot 2. The tile drains discharged into a 4-in. cross main at the east side of the field; the cross main ran into a well in the chalk, outside the field at the north-east corner. To make drainage better on the western half of the field about twelve cross drains were put in under the parallel plot drains. These secondary drains were 3 to 5 ft deep and were led into the nearest dell. Records suggest they discharged into some sort of soakaway dug down to the chalk at the centre of the dell.

The system was originally intended only to drain the land but, because there was one drain under each plot, Lawes and Gilbert realised that they could be used to measure losses of plant nutrients in drainage water from the different fertiliser treatments. Small pits were dug at the intersection of each plot drain and the cross main in December 1866 to sample the runnings from plots 2 to 16. This was not ideal as there was always risk of the sample being contaminated. The drains from plots 17, 18 and 19 were opened

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

TABLE 2·2—continued

in November 1878 and in spring 1879 the arrangements for collecting the runnings were improved. The drain from each plot discharged into its own pit which overflowed into a separate, deepened main drain which was kept open. In 1897–98 this drain was further enlarged, the base concreted and the sides bricked so that it became as it is today.

CULTIVATIONS

Details of cultivations were discussed by Moffatt (1939), and in general terms by Grey (1922) for many years Field Superintendent.

PLOUGHING AND FERTILISER APPLICATIONS. 1844–1914. Previous crop stubble was either shallow ploughed or harrowed and when there was much weed and plant debris this was carted off the plots. Fertilisers and FYM were then applied and the plots reploughed, except 1891–99 when the plots were ploughed immediately after harvest and again just before the fertilisers were applied; the fertilisers were then worked in by harrowing. Seedbed preparation and drilling was always done soon after the second ploughing.

Since 1915 the plots have been ploughed once, after the FYM was applied. The fertilisers were then applied by manure distributor on the partly prepared seedbed, final cultivations were done and the seed drilled. Before about 1880 the seed was usually drilled in November, 1880–1945 usually in October, since 1945 often in November.

N fertilisers have been applied at various times.

1. Ammonium salts, after 1917 ammonium sulphate	*1843–1872*	all in autumn
	1873–1877	all in autumn except plot 15 all in spring
	1878–1883	all in spring except plot 15 all in autumn
	1884–1967	two dressings, 21·5 lb N applied in autumn, balance applied in spring except plot 15 all in autumn.
2. Sodium nitrate	*1867–1967*	always applied all in spring; from 1899 the dressing supplying 86 lb N in two equal amounts, the dates of application differing from 6 days to 6 weeks.

After the drains were put under each plot in the autumn of 1849 (plot 2A was drained in 1884) the field was always ploughed to leave a wide furrow over the drain, the ridges on the outer edges of the plots being spread back on to the plots by hand or by harrowing. The furrows were not cropped. Since 1894 the 'a' and 'b' halves of the plots were cropped and harvested as one plot. Tractors were first used for cultivation in 1920 and for ploughing from 1925; the tractor-mounted one-way plough was used since November 1958.

WEED CONTROL AND FALLOWING. Up to 1914 the plots were hand hoed in most years, wild oats were pulled by hand. In 1889 only alternate rows were sown on the west half of the field to make hoeing easier and in 1890 alternate rows were sown on the east half of the field. In 1904 and 1905 north or south halves of the plots only were cropped and the fallow halves were worked to kill weeds. In 1914 the west halves of all plots were fallowed and in 1915 the east halves. In 1926 the field was divided into five sections; in 1926 and 1927 the eastern two-fifths was cropped, the western three-fifths was fallowed, in 1928 and 1929 the western two fifths was cropped and the eastern three-fifths fallowed. In 1930 all sections were cropped. Since 1931 one section has been fallowed each year and four cropped in a five-year cycle. The arrangement of cropping and fallowing was:

Preliminary fallowing

Harvest year	Section I	II	III	IV	V
1925	C	C	C	C	C
1926	F	F	F	C	C
1927	F	F	F	C	C
1928	C	C	F	F	F
1929	C	C	F	F	F
1930	C	C	C	C	C

Fallow cycle

Harvest year	Section I	II	III	IV	V
1931	F	C	C	C	C
1932	C	F	C	C	C
1933	C	C	C	C	F
1934	C	C	C	F	C
1935	C	C	F	C	C

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

TABLE 2·2—continued

In autumn 1955 section I (due for fallow in 1956) was halved and section IA (west side) reverted to continuous wheat with herbicides from 1957 to control weeds. Since 1963 section VB has grown continuous wheat with herbicides. (Section V was divided in 1954 for a test of liming) Since 1964 herbicides were used on the whole field except section VA. The herbicides used have depended on the weed species emerging in the spring. In 1959, 1960, 1966, and 1967 autumn sprays were used to control weeds.

			Dose per acre		
Crop year	Section of field	Common name	lb	applied in gal. water	Date of application
1957	IA	MCPA‡	1·2 a.e.	80	7 May
1958	IA	mecoprop	2·4 a.e.	40	30 April
1959	IA	TBA	0·25 a.e.	40	12 May
		MCPA	0·75 a.e.		
1960	IA	2,4-D ester	1·53 a.e.	40	8 Sept. 1959
1960	IA	mecoprop	2·25 a.e.	40	28 April
1961	IA	TBA	0·25 a.e.	40	5 May
		MCPA	0·75 a.e.		
1962	IA	TBA	0·25 a.e.	40	24 April
		MCPA	0·75 a.e.		
1963	IA and VB	mecoprop	2·63 a.e.	40	16 May
		2,4-D	0·66 a.e.		
1964	All except VA	dicamba	0·08 a.e.	40	7 May
		MCPA	1·13 a.e.		
1965*	All except VA	dicamba	0·08 a.e.	40	11 May
		MCPA	1·13 a.e.		
1966†	IA and sections IB and II of plot 20	aminotriazole	4·0 a.i.	40	4 Oct. 1965
		ammonium thiocyanate	3·7 a.i.		
1966	All except VA	ioxynil	0·57 a.e.	40	16 May
		mecoprop	1·69 a.e.		
1967	IA	aminotriazole	4·0 a.i.	40	16 Sept. 1966
		ammonium thiocyanate	3·7 a.i.		
1967	All except VA	ioxynil	0·57 a.e.	20	1 May
		mecoprop	1·69 a.e.		

(a.e. acid equivalent, a.i. active ingredient)

NOTE: Autumn applications were all to the stubble, spring applications to the growing crop. No weedkiller was applied to fallow land.

* On 22 October 1964 various perennial grasses were forked out by hand on plots 10, 16, 19 and 20 (section IA).

† On 13 October 1965 patches of coltsfoot (*Tussilago farfara*) were cultivated and the plants forked out.

‡ Potassium, sodium or amine salt formulations of acids unless otherwise stated.

HARVESTING. Plots were originally cut by hand; they were first cut by a self binder in 1902, but hand cutting with scythes was often necessary when the ground was very wet or the crop badly laid. Sheaves from each plot were stooked on that plot, carted, stored and then threshed during the winter. Since 1957 plots were harvested by combine-harvester, yield was estimated by weighing 1 cut only, the rest cleared as discard. Before 1957 the plots were usually cut in early August and the sheaves stood on the plots for about two weeks. Since 1957 combining has been at the end of August or in early September.

https://doi.org/10.23637/ERADOC-1-2

This work is licensed under a Creative Commons Attribution 4.0 International License.

TABLE 2·2—continued

CROPPING

Some part of every plot has grown winter wheat each year.

Seed rates ranged from 110–190 lb/acre.

Row spacing	*1844–1862*	rows at 12·5 in. (12 rows on a land)
	1863–1893	rows at 7·8 in. (18 rows on a land, i.e. each 'a' and 'b' half plot except 1889 and 1890, see section on weed control)
	1894–1905	rows at 8·9 in. (28 rows on the 'new' wide plots)
	1906–1927	rows at 12 in. (20 rows/plot except 1913 rows at 7·6 in.)
	1928–1967	rows at 7 in.
Varieties	*1844–1848*	Old Red Lammas
	1849–1852	Old Red Cluster
	1853–1881	Red Rostock
	1882–1899	Red Club
	1900–1916	Squarehead's Master, except 1905 Giant Red, 1910 Browick Red, 1911–12 Little Joss
	1917–1945	Red Standard except 1929, 1940, 1941, 1943 Squarehead's Master; 1942, Stand up.
	1946–1967	Squarehead's Master 13/4, for 1963–67 grain from several plots was bulked each year, well mixed and used as seed.

Seed dressings. In 1912 the seed was dressed with copper sulphate and in 1923 and 1924 it was treated with formalin. From 1932 seed treated each year with various seed dressings, 1932–62 organo mercurials with or without insecticide (BHC), from 1963 mercurials only.

https://doi.org/10.23637/ERADOC-1-2