Rothamsted Experimental Station - Guide to the Experimental Plots 1906


Rothamsted Experimental Station
Harpenden

Guide to the Experimental Plots

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LAWES AGRICULTURAL TRUST

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COMMITTEE OF MANAGEMENT

DIRECTOR

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INTRODUCTION

Mr (afterwards Sir) John Bennet Lawes was the founder of the Rothamsted Experimental Station. He began experiments with various manurial substances, first with plants in pots and then in the field, soon after entering into possession of the estate of Rothamsted in 1834. In 1843 more systematic field experiments were begun, and the services of Dr (afterwards Sir) J. H. Gilbert were obtained as Director, thus starting the long association which only terminated with the death of Sir John Lawes in 1900, followed by that of Sir Henry Gilbert in 1901.

The Rothamsted Experimental Station has never been connected with any external organisation, but has been maintained entirely at the cost of Sir John Lawes. In 1889 he constituted a trust for the continuance of the investigations, setting apart for that purpose the laboratory (which had been built by public subscription, and presented to him in 1855), certain areas of land on which the experimental plots were situated, and £100,000.

By the provisions of the trust-deed, the management is entrusted to a committee nominated by the Royal Society (four persons), the Royal Agricultural Society (two persons), the Chemical and Linnean Societies (one each), and the owner of Rothamsted.

The field experiments, which began in 1843, have on some of the plots been continued without break or alteration up to the present day; on the Broadbalk wheat field certain rearrangements were made in 1852, in which year also the barley experiments on the Hoos field began. The leguminous crops on the Hoos field were started in 1848, the experiments on roots have been continued on the same field since 1843, and on the same plan since 1856. The grass plots began in 1856, and the rotation experiments in 1848.

It should be remembered that the object of the Rothamsted experiments is to ascertain "how the plant grows," and only indirectly to find the most paying method and manuring; hence both the nature and the quantities of material applied are not to be taken as indicating the manures to be used in practice.

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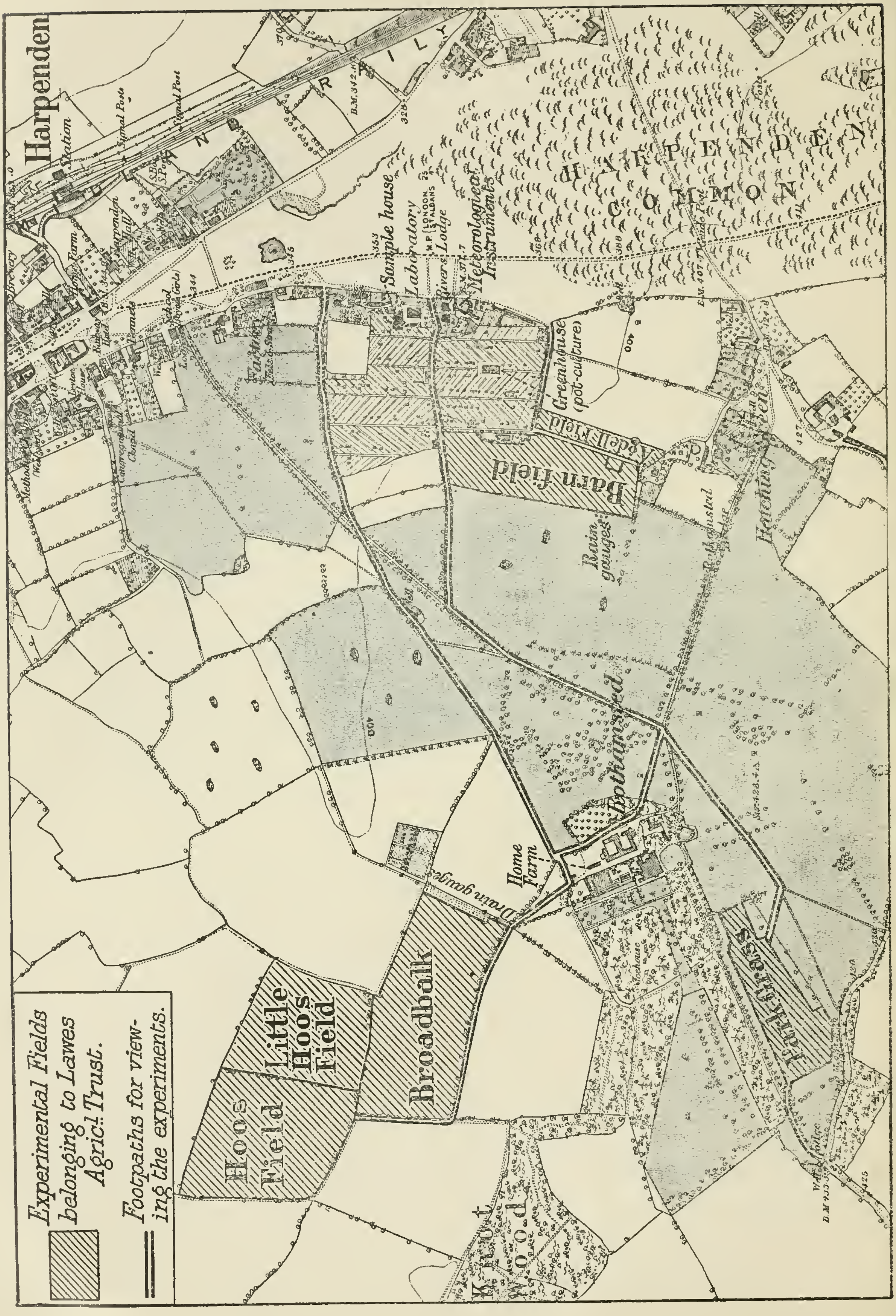

Harpenden
Station
Harpenden Common
Sample house
Laboratory
Lodge
Meteorological Instruments
Greenhouse (pot-culture)
Barn field
Rain gauges
Rothamsted
Home Farm
Drain gauges
Broadbalk
Little Hoos Field
Hoos Field
Hatching Green
Experimental Fields belonging to Lawes Agric! Trust.
Footpaths for viewing the experiments.

THE ROTHAMSTED SOIL

The Rothamsted soil was described by Lawes in 1847, as follows:—"The soil upon which my experiments were tried consists of rather a heavy loam resting upon chalk, capable of producing good wheat when well manured; not sufficiently heavy for beans, but too heavy for good turnips or barley. The average produce of wheat in the neighbourhood is said to be less than 22 bushels per acre, wheat being grown once in five years. The rent varies from 20s. to 26s. per acre, tithe free."

It is fairly uniform in the different fields, and consists essentially of a heavy loam containing little coarse sand or grit, but a considerable amount of fine sand and silt, and a large body of clay. In consequence, the soil has to be worked with care, becoming very sticky and drying to impracticable clods if moved when wet. It "runs together" if heavy rain falls after a tilth has been established, and then dries with a hard, unkindly surface, these difficulties being much exaggerated on the plots which have been farmed for a long time without any supply of organic matter in the manures.

The most notable feature in the Rothamsted soil is the amount of calcium carbonate in the surface layer; analyses of the earliest samples available (1856) show more than 5 per cent. in the surface soil of Broadbalk field. The subsoil below the depth of 9 inches contains little or no calcium carbonate, and this fact, together with the varying proportion in the surface soil, indicate that the original soil was almost devoid of calcium carbonate, and that the quantity now found in the surface soil has all been applied artificially.

AGDELL FIELD

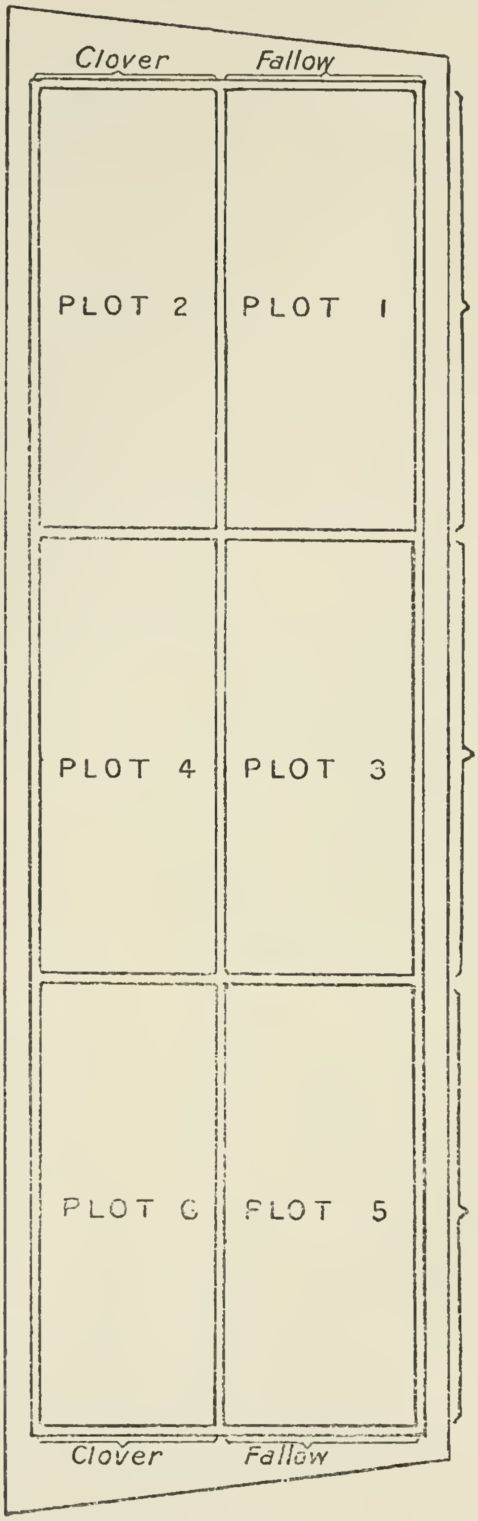
Crops grown in Rotation

The Agdell field, which was put under experiment in the year 1848, differs from the other Rothamsted fields in that it is farmed on a four-course rotation of Swedes, barley, clover (or beans) or fallow, and wheat, instead of growing one crop continuously. It is divided into three main plots, one of which (O) has received no manure, the second (M) mineral manures only, and the third (C) a complete manure, containing the same minerals, but also nitrogen in the form of rape cake and ammonium-salts. The manures are applied to the Swedes only, the other three crops of each course being grown without manure. Each of the three plots is further subdivided:—Half the plots carry clover or beans as the third crop of the course, and half the plots are bare fallow. This shows the effect of introducing the leguminous crop into the rotation, as compared with the bare fallow.

On this field the long-continued cropping without manure on O affects the successive crops in the rotation very differently. The Swede crop is least capable of growing in the impoverished soil, and is reduced to less than a ton per acre; the clover and barley crops are also small, but the deep-rooted wheat crop is comparatively little affected, and yielded as much as 19·6 bushels per acre in 1903, the fifty-sixth year without any

A.—*Plan of the Plots in Agdell Field on which Experiments have been made on Four-Course Rotation.*

1848 and onwards.



C. *Complete Manure for Root Crop.*
As "M" and
200 lb. Ammonium-salts, and
2000 lb. Rape Cake
per acre.

M. *Minerals only for Root Crops.*
500 lb. Superphosphate,
500 lb. Sulphate of Potash,
100 lb. Sulphate of Soda,
200 lb. Sulphate of Magnesia,
per acre.

O.
Unmanured.

Total area of ploughed land, about 3 acres. Area of each of the 6 divisions, $\frac{2}{5}$ acre.

The 2 lower divisions, Unmanured continuously (Plots 5 and 6).
The 2 middle divisions, Mineral Manure, for the Roots, each Course (Plots 3 and 4).
The 2 upper divisions, Mineral and Nitrogenous Manure, for the Roots, each Course (Plots 1 and 2).
The 3 left-hand divisions, Clover (or Beans), 3rd year each Course.
The 3 right-hand divisions, Fallow, 3rd year each Course.

The double lines indicate division paths between plot and plot.

manure. With minerals, but without nitrogen, the Swedes continue to give a fair crop; the barley and wheat are but little better than on the unmanured plot, while the clover grows almost as freely as on the completely manured plot.

TABLE I.—*Effect of Manure on Crops grown in rotation, Agdell Field. Average produce per acre over the five last Courses*, 1884-1903.

		O. Unmanured.	M. Mineral Manures.	C. Complete Manure.
Roots (Swedes)	Cwt.	15·9	208·2	399·9
Barley Grain	Bush.	15·8	20·0	27·7
Barley Straw	Cwt.	11·3	12·7	18·5
Clover Hay *	Cwt.	9·4	35·5	37·8
Bean Corn †	Bush.	15·9	28·3	19·6
Bean Straw †	Cwt.	8·8	17·0	11·5
Wheat Grain	Bush.	26·2	36·1	37·1
Wheat Straw	Cwt.	20·8	31·1	33·0

* Average of 3 courses. † Average of 2 courses.

TABLE II.—*Crops grown in rotation, Agdell Field. Produce per acre over the last complete Course* (14*th*), 1900-1903.

Year.	Crop.		O. Unmanured.		M. Mineral Manure.		C. Complete Mineral and Nitrogenous Manures.	
			5. Fallow.	6. Beans or Clover.	3. Fallow.	4. Beans or Clover.	1. Fallow.	2. Beans or Clover.
1900	Roots (Swedes)	Cwt.	44·8	15·8	201·6	272·1	480·6	480·0
1901	Barley Grain	Bush.	16·3	22·1	15·9	22·3	25·1	29·4
1901	Barley Straw	Cwt.	9·1	13·8	9·3	12·9	15·8	17·5
1902	Clover Hay	Cwt.	...	0·1	...	3·7	...	6·1
1903	Wheat Grain	Bush.	20·3	18·9	21·9	28·9	23·6	27·9
1903	Wheat Straw	Cwt.	17·9	16·2	24·9	32·4	28·4	32·2

When the plots 2 and 4 grow a good crop of clover, the residues of the crop have a very beneficial effect upon the succeeding crops of the rotation, as compared with the crops of plots 1 and 3, which are bare fallowed; the wheat is increased by something like 15 per cent., the roots (although manured) are slightly better, and the barley, following the roots, still shows the value of the preceding clover crop. No such residue seems to be left behind by the bean crop, whenever that is taken in the rotation instead of clover. On the unmanured plot 6, only, the clover shows no effect on succeeding crops, because there its growth is too small to leave behind any residue of nitrogen.

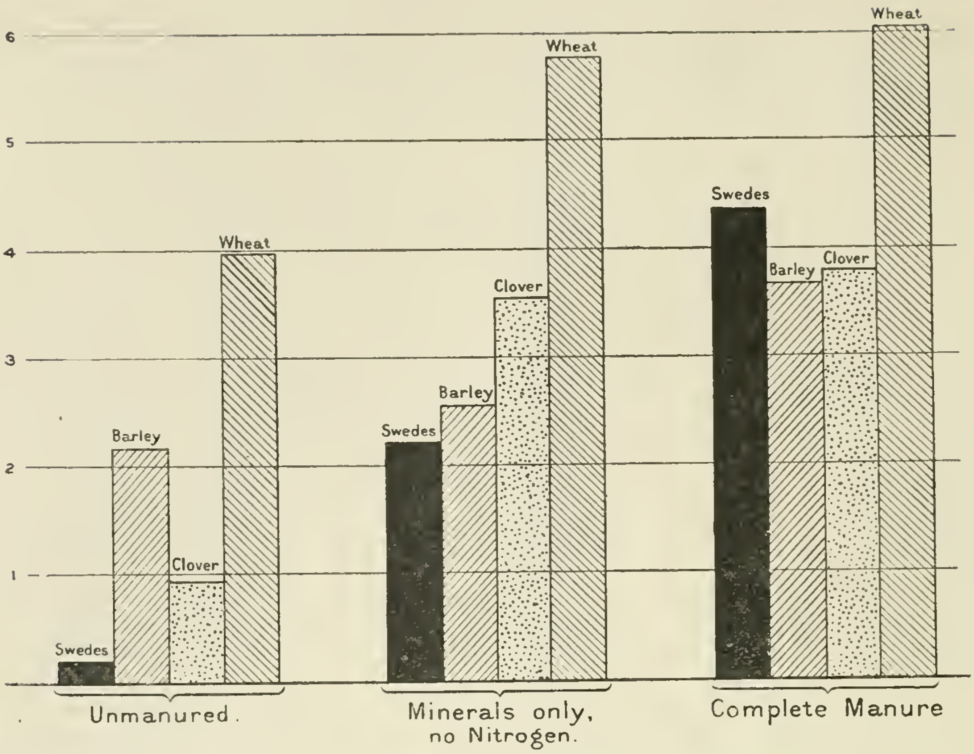


FIG. 1.—Effect of Manure upon Crops grown in Rotation. Total Produce. Averages of Five Courses (1884-1903). Swedes in 100 cwt.; Barley and Wheat in 1000 lb.; and Clover in 10 cwt.

TABLE III.—*Crops grown in rotation, Agdell Field. Effect of the largest Clover or Bean Crop on the following Wheat Crop. Total produce per acre.*

	Clover, 1894.	Wheat, 1895. After Fallow.	Wheat, 1895. After Clover.	Wheat, 1895. Difference due to Clover.	Beans, 1862.	Wheat, 1863. After Fallow.	Wheat, 1863. After Beans.	Wheat, 1863. Difference due to Beans.
	Cwt.	Lb.	Lb.	Per cent.	Lb.	Lb.	Lb.	Per cent.
O. Unmanured	16·5	3131	3193	+ 2·0	3603	7222	5281	– 26·9
M. Mineral Manure	59·7	4220	5180	+ 22·7	4033	7910	6090	– 23·0
C. Complete Manure	76·7	4547	5209	+ 14·6	5755	8792	7674	– 12·7

TABLE IV.—*Crops grown in rotation, Agdell Field. Effect of Clover or Beans on the following Wheat Crops. Total produce per acre.*

	Clover Crops.*	Wheat.† After Fallow.	Wheat.† After Clover.	Wheat.† Difference due to Clover.	Bean Crops.‡	Wheat.§ After Fallow.	Wheat.§ After Beans.	Wheat.§ Difference due to Beans.
	Cwt.	Lb.	Lb.	Per cent.	Lb.	Lb.	Lb.	Per cent.
O. Unmanured	15·2	4173	3475	– 16·7	1888	4907	4373	– 10·9
M. Mineral Manure	44·4	5245	5613	+ 7·0	2615	5528	5447	– 1·5
C. Complete Manure	52·9	5479	6130	+ 11·9	3177	6092	5929	– 2·7

* 5 years (1874, 1882, 1886, 1894, and 1902).
† 5 years (1875, 1883, 1887, 1895, and 1903).
‡ 8 years (1854, 1858, 1862, 1866, 1870, 1878, 1890, and 1898).
§ 8 years (1855, 1859, 1863, 1867, 1871, 1879, 1891, and 1899).

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The diagram, Fig. 2, shows in a graphic form the benefit the whole rotation receives from the growth of clover, even when the root crop receives nitrogenous manures.

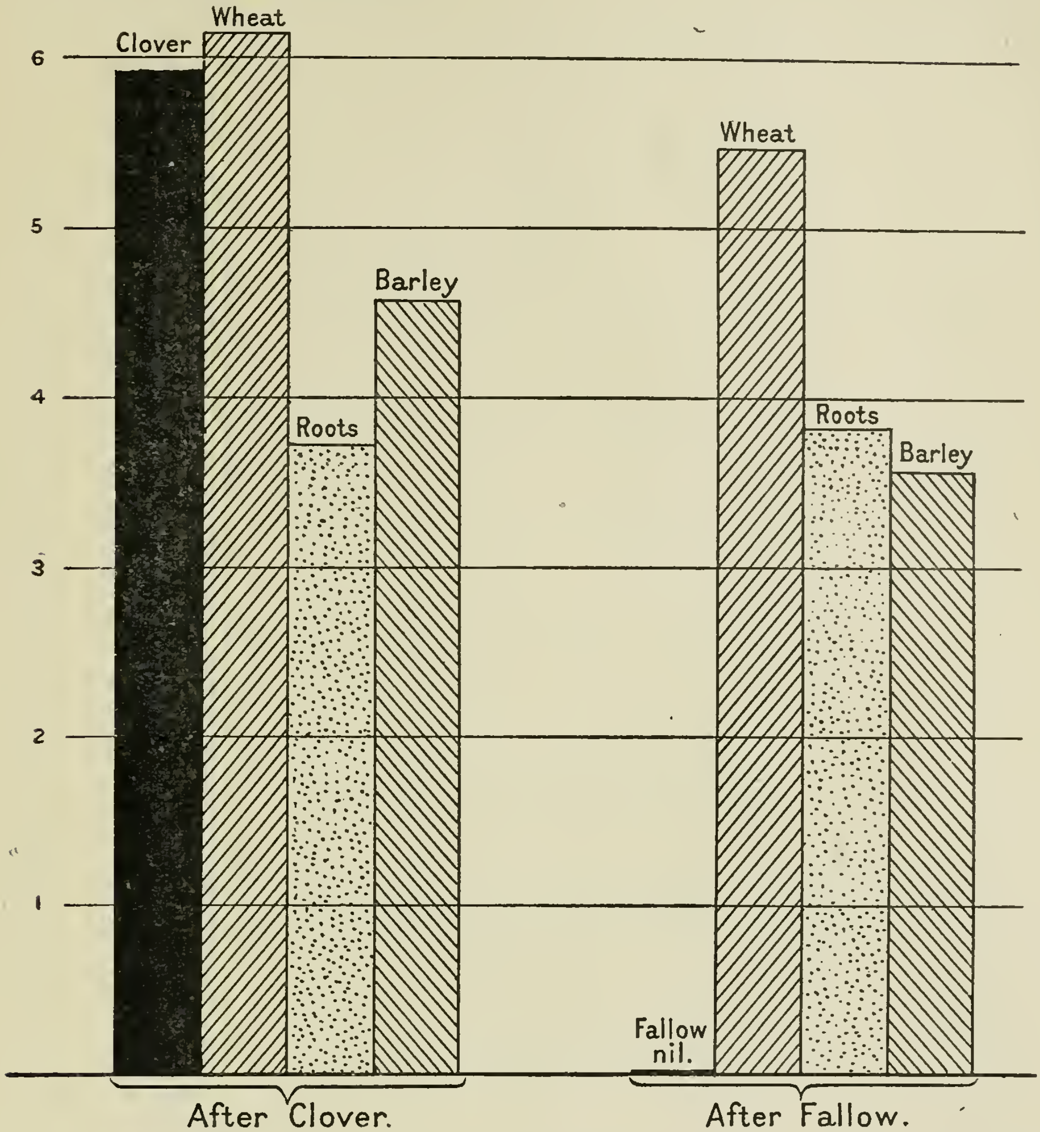

FIG. 2.—Comparative Effect of Clover or Bare Fallow on the succeeding Crops in the Rotation. Total Produce—In 1000 lb. for Clover, Wheat, and Barley, and in 100 cwt. for Roots.

BARN FIELD

Mangel Wurzel

The experiments upon mangels began in 1876, but the land had been receiving similar manures for other root crops since 1856.

The field is divided longitudinally into eight strips running the whole length of the field; each of these strips receives one manure throughout its length; farmyard manure alone on Strip 1, and in combination with superphosphate and sulphate of potash on Strip 2, nothing on Strip 8, superphosphate alone on Strip 5, superphosphate and sulphate of potash on Strip 6, and complete minerals, including sulphate of magnesia and

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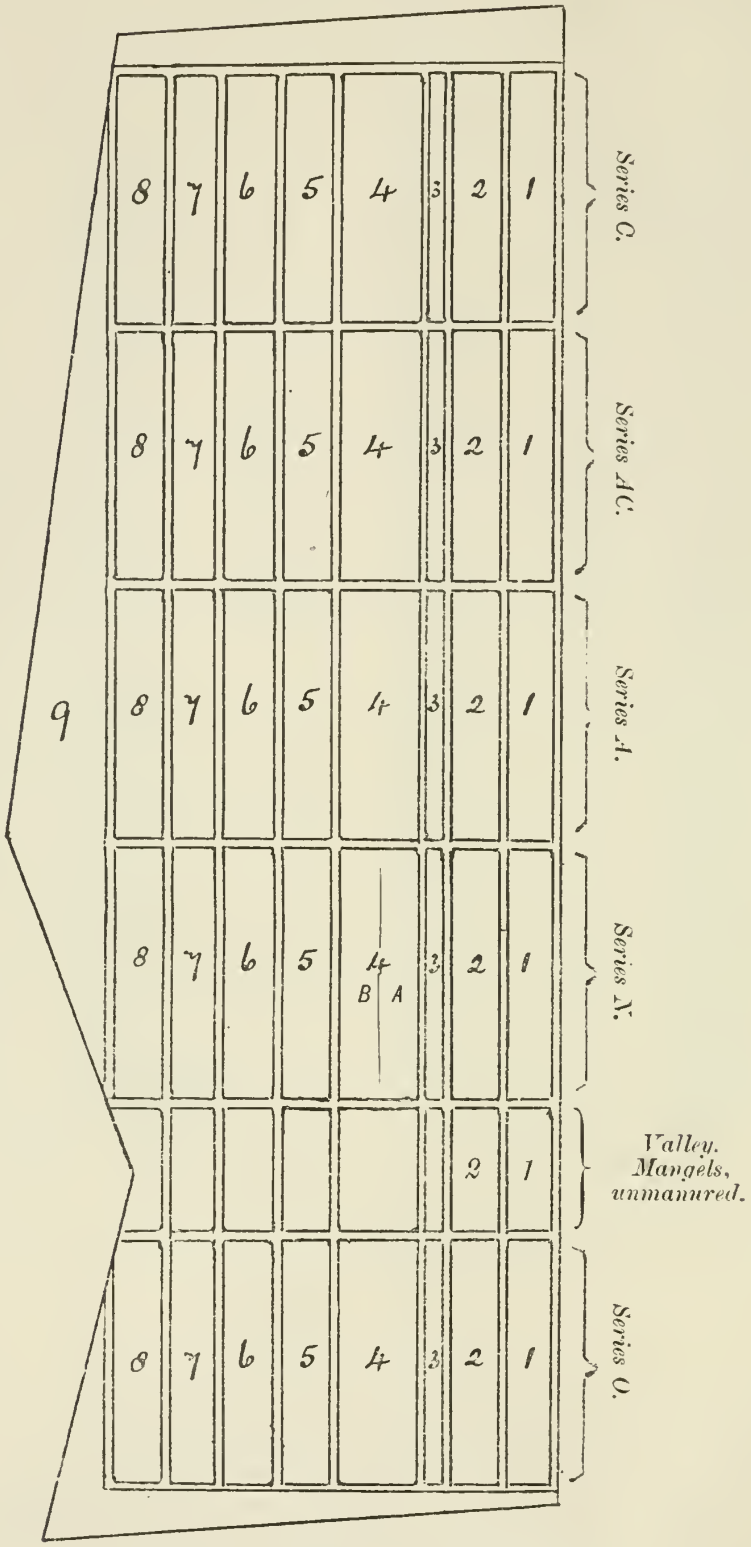
B.—*Plan of the Plots in Barn Field on which Experiments have been made with Root Crops.*

1843 and onwards.



Total area of ploughed land, about 8 acres.

Area of Plots:
- 1, 2, 5, 6, 7, and 8, of each Series, rather over $\frac{1}{7}$ acre.
- 3, of each Series, about $\frac{1}{27}$ acre.
- 4, of each Series, about $\frac{1}{5}$ acre.
- 9, rather over $\frac{4}{10}$ acre.

The double lines indicate division paths between plot and plot.

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common salt, on Strip 4. The strips are then subdivided into plots by cross-dressings of nitrogenous manures; nothing on the O Series, nitrate of soda on Series N, ammonium-salts on Series A, rape cake on Series C, and a combination of ammonium-salts and rape cake on Series AC.

TABLE V.—*Experiments on Mangel Wurzel, Barn Field, beginning* 1876. *Quantities of Manures per acre per annum.*

Strip.	Strip Manures					Nitrogenous Manures running across all the Strips.					
						Series O.	N.	A.	AC.		C.
	Farmyard Manure.	Superphosphate.	Sulphate of Potash.	Sulphate of Magnesia.	Chloride of Soda. (Salt.)	None.	Nitrate of Soda.	Ammonium-salts.*	Rape Cake.	Ammonium-salts.*	Rape Cake.
	Tons	Cwt.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
1	14	...	...	...	...	...	550	400	2000	400	2000
2	14	3·5	500†	...	...	...	550	400	2000	400	2000
4	...	3·5	500	200	200	...	550	400	2000	400	2000
5	...	3·5	...	...	...	...	550	400	2000	400	2000
6	...	3·5	500	...	...	...	550	400	2000	400	2000
7‡	...	3·5	...	200	200	...	550	400	2000	400	2000
8	...	...	...	...	...	...	550	400	2000	400	2000

* Equal parts Sulphate and Muriate Ammonia of Commerce.
† The addition of Potash to Plot 2 began in 1895. ‡ Commenced in 1903 only.

TABLE VI.—*Barn Field Mangel Wurzel. Produce of Roots and Leaves per acre. Season* 1905.

Strip.	Strip Manures.	Cross-Dressings.				
		O.	N.	A.	AC.	C.
		None.	Nitrate of Soda.	Ammonium-salts.	Rape Cake and Ammonium-salts.	Rape Cake.
		Tons.	Tons.	Tons.	Tons.	Tons.
1	Dung only . . .	R. 21·04 L. 4·05	33·52 5·61	24·80 5·50	25·93 5·91	24·12 5·61
2	Dung, Super., Potash .	R. 21·83 L. 4·06	33·75 5·76	30·27 6·68	31·59 7·36	29·54 5·83
4	Complete Minerals .	R. 3·23 L. 1·07	22·30 * 24·69 4·42 * 5·43	17·96 3·30	31·62 7·06	23·86 3·88
5	Superphosphate only .	R. 3·75 L. 1·34	17·49 4·27	6·74 3·54	8·88 3·96	11·13 3·80
6	Super. and Potash .	R. 3·07 L. 1·06	20·42 3·80	18·02 3·82	25·47 7·23	20·91 3·76
7	Super., Sulph. Mag., and Chloride Sodium .	R. 3·47 L. 1·23	22·69 4·65	19·43 3·96	28·53 7·60	22·45 4·41
8	None	R. 2·68 L. 1·21	9·55 4·55	5·29 3·89	8·60 4·36	8·02 3·52

* Received an equivalent amount of Phosphoric Acid, Nitrogen, and Potash, but without any Soda Salts.

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The value of farmyard manure in growing mangels is evident, especially when they are grown continuously on the same land. In favourable seasons it is possible to obtain good crops by the aid of manures containing no organic matter, as seen in 1905; but in ordinary years the bad texture of the soil which results, and its tendency to lose water on account of the lack of humus, affect both the germination of the seed and the growth of the plant in its early stages.

TABLE VII.—*Barn Field Mangel Wurzel. Average produce of Roots per acre over 27 years* (1876 *to* 1902).

Strip.	Strip Manures.	Cross-Dressings.				
		O.	N.	A.	AC.	C.
		None.	Nitrate of Soda.	Ammonium-salts.	Rape Cake and Ammonium-salts.	Rape Cake.
		Tons.	Tons.	Tons.	Tons.	Tons.
1	Dung only . . .	17·44	24·74	21·73	24·05	23·96
2	Dung, Super., Potash* .	17·95	25·19	22·35	24·91	24·43
4	Complete Minerals .	5·36	18·01	14·86	25·49	21·33
5	Superphosphate only .	5·21	15·40	7·66	10·38	11·13
6	Super. and Potash .	4·55	15·38	14·03	22·48	18·63
8	None	3·91	10·24	5·89	9·84	10·00

* The addition of Potash to Plot 2 only began in 1895.

Effect of Nitrogen

To ascertain the effects of nitrogen, it is best to examine Strip 4, which receives a complete mineral manure with different compounds of nitrogen. Series A, which receive ammonium-salts, should also be compared with Series N, receiving nitrate of soda. The general superiority of nitrate of soda as a nitrogenous manure for mangels is most strikingly seen on Plots 5, where potash is omitted.

The diagram, Fig. 3, shows on the left hand the average results obtained with the varying amounts and compounds of nitrogen on the Plots 4 in question, where there is an abundant supply of mineral manure. The right-hand half of the diagram shows the effect of the same nitrogenous manures when used in conjunction with dung instead of complete minerals.

The injurious effects of the very large amounts of nitrogen added to some of the plots is very manifest wherever there is more nitrogen than the plant can properly deal with. The leaves have a dark green appearance, are much curled and crinkled, and show an increased tendency to variegation, the chlorophyll collecting into dark green or almost black blotches on the lighter background of the leaf. The leaf stalks are often much more coloured, and become a bright orange yellow.

On these plots the leaves do not ripen off and obtain the general yellow flaccid appearance presented on the more healthy plots when the crop is ready to lift; instead, the outer leaves begin to die and shrivel up quite early in October; in some places they show numbers of dead spots and burnt-looking patches round the edges of the leaf.

Thus, towards the end of October, the plots receiving the excess of nitrogen present a very unhealthy appearance; a large proportion of the plants seem scorched and withered as regards the outer leaves, and only show a cluster of small dark green active leaves at the heart.

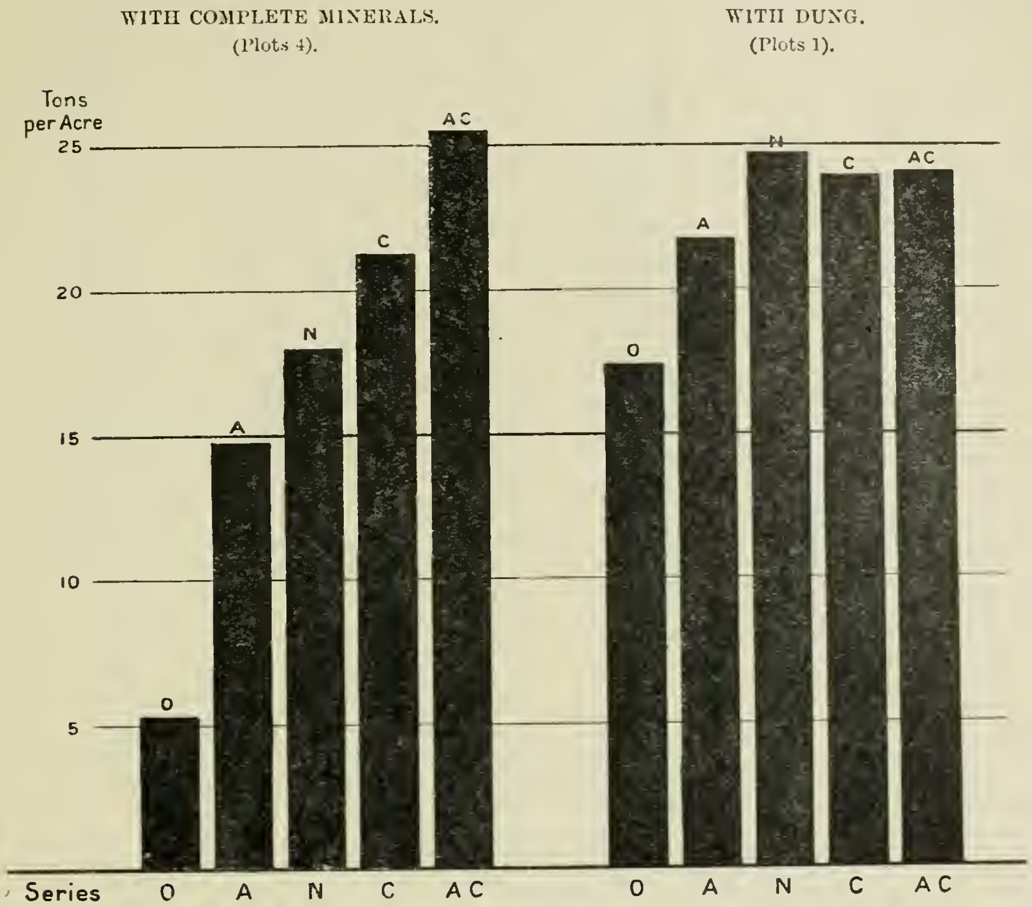

Fig. 3.—Mangel Wurzel. Effect of increasing amounts of Nitrogen. Average Produce of Roots per acre, 1876-1902.

O = No Nitrogenous Manure.
A = 86 lb. Nitrogen as Ammonium-salts.
N = 86 lb. Nitrogen as Nitrate of Soda.
C = 98 lb. Nitrogen as Rape Cake.
AC = 98 lb. Nitrogen as Rape Cake, and 86 lb. Nitrogen as Ammonium-salts.

Effect of Mineral Manures

The effect of the different mineral constituents of a manure upon the mangel crop can be seen by an examination of Plots 4, 5, and 6.

The great increase of crop comes as a rule when potash is added to the superphosphate, and is to be correlated with the fact that the mangel is essentially a sugar-producing plant, and that large supplies of potash seem to be essential to the processes in the plant which result in the formation of sugar and similar carbohydrates.

The effect of potash and of the other saline manures is plainly visible in the appearance of the plants themselves. On the plots receiving potash the plant begins to ripen early, the leaves turn yellow and become flaccid, so that in October these plots may be seen outlined from the rest by their lighter tint.

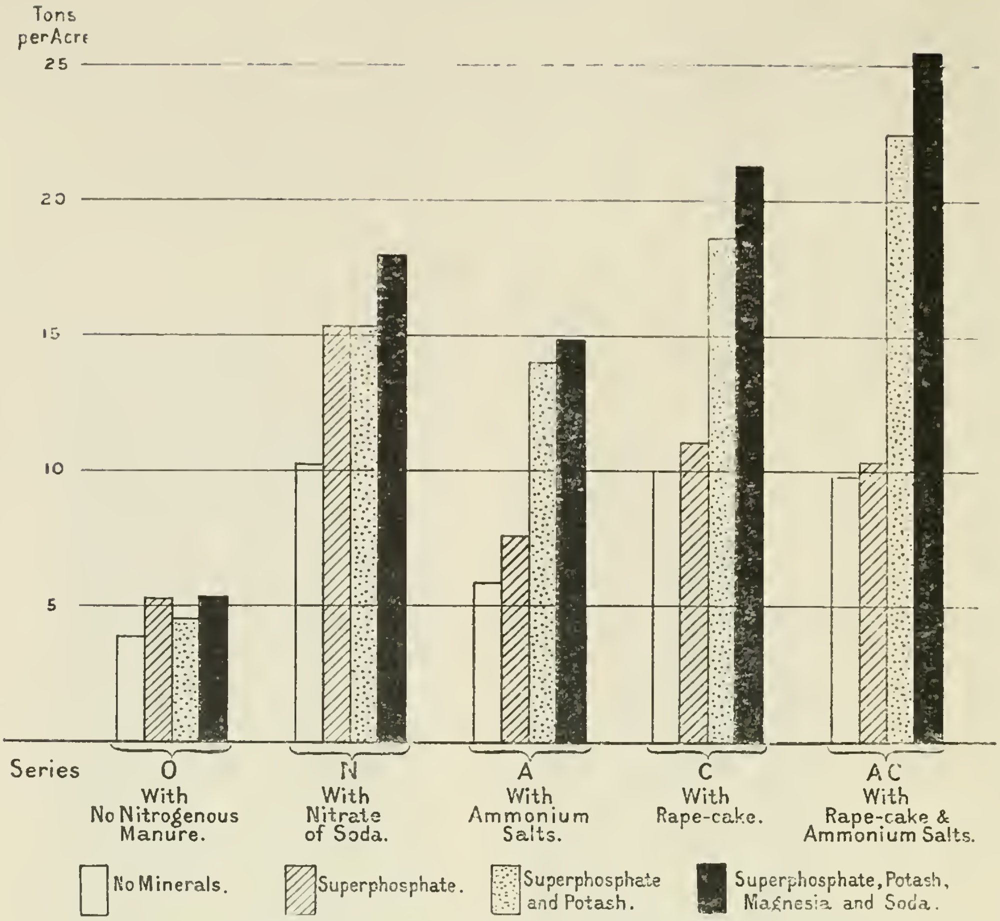

FIG. 4.—Mangel Wurzel. Effect of various Mineral Manures. Average Produce of Roots per acre, 1876-1902.

Effect of Artificial Manures with Dung

A comparison of Strip 2 with Strip 1 shows the effect of adding superphosphate and sulphate of potash to the dung and nitrogenous manures applied to Strip 1. A heavier crop and a healthier plant is obtained, especially where a large amount of nitrogenous manure is used. Since in the earlier experiments it was found that superphosphate had no beneficial effect when used with dung we can put down the superiority of Strip 2 over Strip 1 to the sulphate of potash which is now used.

Effect of Manures upon the Texture of the Soil

On the strong Rothamsted soil several of the manures employed have an injurious action upon the texture of the soil and often prevent a satisfactory tilth being obtained in the spring, to the great injury of the crop. This is particularly seen where no organic manure is used, both dung and rape cake tend to keep the land in good condition. Of the artificial manures nitrate of soda and sulphate of potash have the worst effect upon the land, making it very sticky when wet, and hard and caked when dry. Superphosphate on the contrary promotes a friable tilth.

METEOROLOGICAL OBSERVATIONS

The rainfall has been measured at Rothamsted since February 1853 in a 5-inch funnel gauge, and in a rectangular gauge (7 feet 3·12 inches by 6 feet), having an area of one-thousandth acre.

In addition to these gauges, an 8-inch Board of Trade gauge has been employed since January 1881. The ground on which the gauges are situated is 420 feet above sea-level.

The amount of water percolating through bare soil has been measured since 1870 by means of three drain-gauges, each having an area of one-thousandth acre. These were constructed by undermining the soil at the desired depths—20, 40, and 60 inches respectively—and inserting perforated iron plates to support the soil. When this was completed, trenches were cut round the blocks of soil, and these were then isolated by means of brick and cement walls. The external soil was then returned. The percolating water falls on to zinc funnels, from which it passes to the measuring cylinders.

Barometric and temperature records have been kept since 1873, and since July 1891 daily observations of the bright sunshine have been made by means of a Campbell-Stokes recorder.

The average yearly rainfall as measured at Rothamsted during the fifty-one years, 1853-1903, is 28·21 inches.

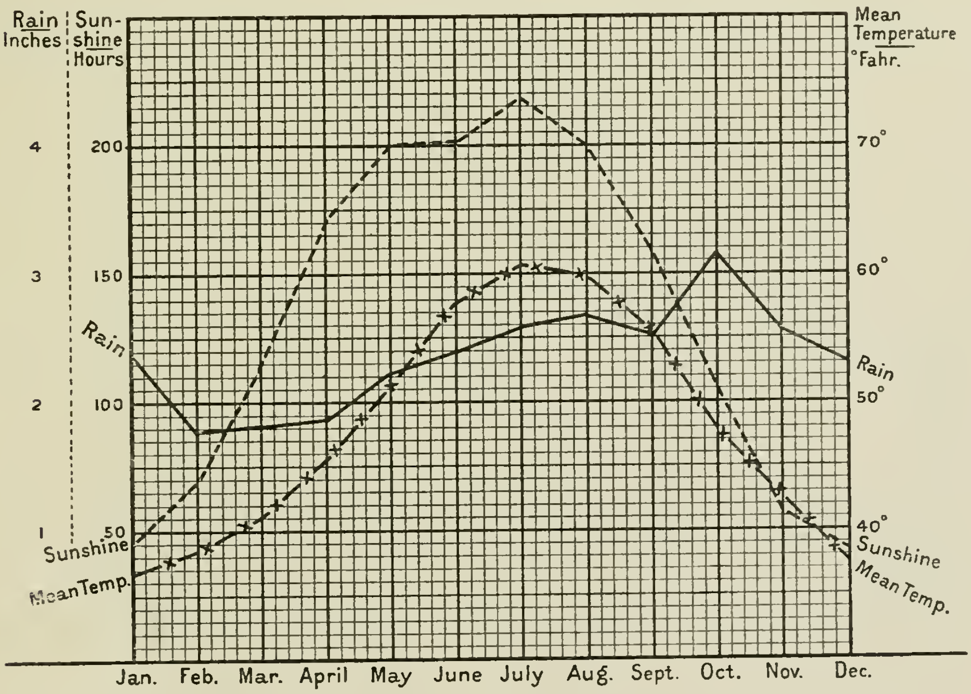

FIG. 5.—Rainfall: Average of 51 years (1853-1903).
Sunshine: Average of 11 years (1892, 1893, and 1895-1903).
Mean Temperature: Average of 26 years (1878-1903).

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TABLE VIII.—*Meteorological Summary.*

	Rainfall. Average, 51 years (1853-1903).			Bright Sunshine. Average, 11 years (1892, 1893, and 1895-1903).				Temperature. Average, 26 years (1878-1903).		
	Total Fall.	Rainy Days.		Total.	Per cent.	Days with 0·1 hour, or more.		Means.		Min. and Max. combined.
		Actual.	Per cent.			Actual.	Per cent.	Minimum.	Maximum.	
	Inches.	No.		Hours.		No.		°F.	°F.	°F.
January	2·35	16	52	46·4	19	16	51	31·5	41·6	36·6
February	1·78	13	47	69·2	25	19	66	32·5	43·9	38·2
March	1·81	13	42	114·6	32	26	85	33·5	48·3	40·9
April	1·86	13	43	170·3	42	27	91	36·8	54·2	45·5
May	2·22	13	42	199·9	41	29	93	42·2	60·2	51·2
June	2·39	12	41	201·9	41	27	91	48·4	66·6	57·5
July	2·58	13	43	217·5	44	29	95	51·7	69·7	60·7
August	2·67	14	44	201·1	45	30	96	51·4	68·5	59·9
September	2·51	13	44	158·3	43	27	92	47·6	64·1	55·9
October	3·16	18	57	106·1	32	25	79	41·1	54·8	48·0
November	2·57	17	55	57·0	22	18	58	36·8	48·3	42·6
December	2·31	16	52	43·2	18	16	51	32·4	42·9	37·7
Whole year	28·21	171	47	1585·5	36	289	79	40·5	55·3	47·9

TABLE IX.—*Rainfall and Drainage, etc., at Rothamsted,* 1905.

	Rain.			Drainage.			Bright Sunshine.	Temperature.	
	Total Fall.		Number of Rainy Days.	Soil 20 ins. deep.	Soil 40 ins. deep.	Soil 60 ins. deep.		Max.	Min.
	5-inch Funnel Gauge.	1/1000th Acre Gauge.	1/1000th Acre Gauge.						
	Inches.	Inches.	No.	Inches.	Inches.	Inches.	Hours.	°F.	°F.
January	1·292	1·339	10	0·703	0·772	0·755	83·6	43·1	31·7
February	0·944	0·951	11	0·225	0·234	0·218	78·4	46·3	36·1
March	3·487	3·573	22	2·422	2·540	2·482	125·9	51·3	36·9
April	2·155	2·215	22	0·558	0·549	0·588	100·5	52·6	38·7
May	1·082	1·125	8	0·069	0·073	0·104	244·1	61·3	41·5
June	3·893	4·054	15	1·259	1·382	1·382	169·1	66·2	50·7
July	1·402	1·473	10	0·232	0·310	0·352	264·8	73·4	55·0
August	3·342	3·459	20	0·976	0·919	0·918	180·1	67·0	50·3
September	2·143	2·248	12	0·713	0·739	0·702	129·2	61·5	47·9
October	1·583	1·665	16	0·393	0·320	0·306	113·8	51·3	37·7
November	3·127	3·231	20	2·664	2·753	2·644	60·0	46·6	33·6
December	1·057	1·103	13	0·836	0·990	0·963	30·4	43·9	34·5
Total or Mean	25·507	26·436	179	11·050	11·581	11·414	1579·9	55·4	41·2

THE PARK

Grass Land Mown for Hay every Year

The experiments upon grass at Rothamsted began in 1856, about 7 acres of the park close to the house being set aside for the purpose. The land has been in grass as long as any recorded history of it exists, for some centuries at least. It is not known that seed has ever been sown, and at the beginning of the experiments the herbage on all the plots was apparently uniform.

The plots, of which there are twenty in all, vary somewhat in size, which lies between one-half and one-eighth of an acre. Up to 1874 inclusive the grass was only cut once, the aftermath being fed off by sheep. Since that time there has been no grazing, and the plots are generally cut twice in the year. The grass is made into hay in the usual way, and the whole produce of each plot is then weighed.

TABLE X.—*Manuring of the Permanent Grass Plots per acre per annum, 1856 and since.*

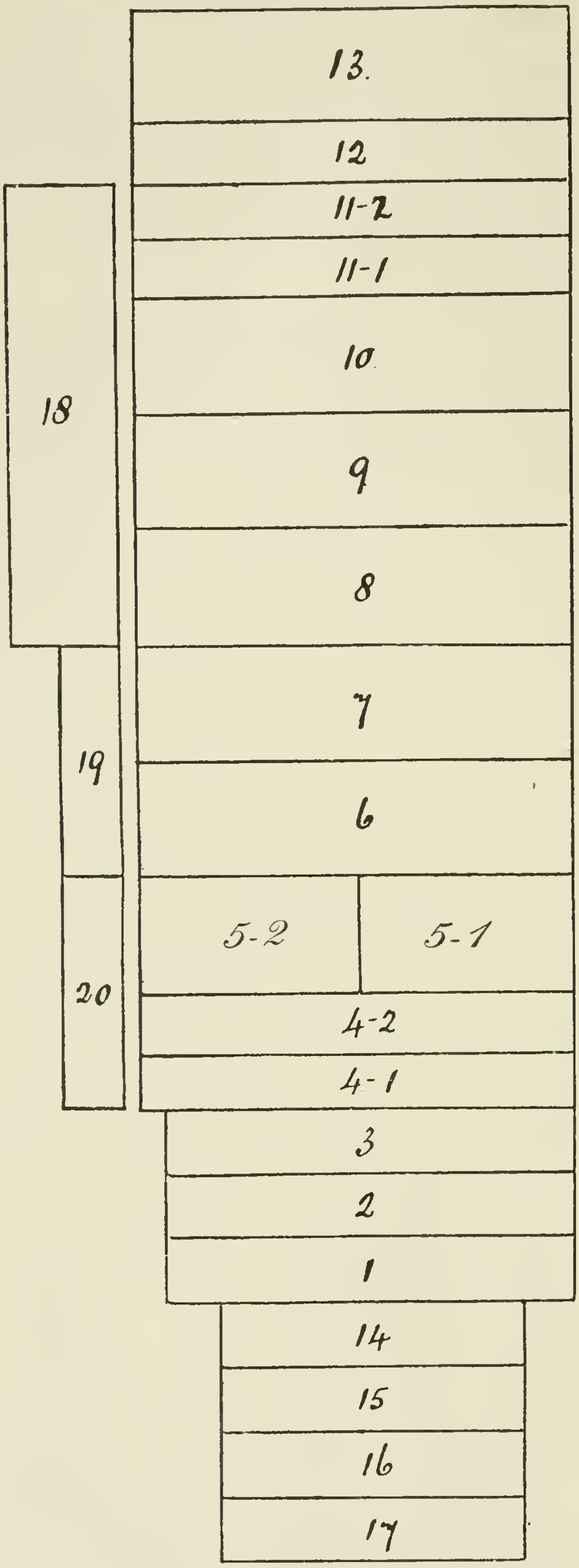
Plot	Abbreviated Description of Manures.	Nitrogenous Manures.		Mineral Manures.				
		Ammonium-salts.	Nitrate of Soda.	Super-phosphate.	Sulphate of Potash.	Sulphate of Soda.	Sulphate of Magnesia.	Silicate of Soda.
		Lb.	Lb.	Cwt.	Lb.	Lb.	Lb.	Lb.
3, 12	Unmanured every year	...	...	...	...	...	...	...
2	Unmanured; following Dung first 8 years	...	...	...	...	...	...	...
1	Ammonium-salts alone; with Dung also first 8 years	200	...	...	...	...	...	...
4-1	Superphosphate of Lime	...	...	3·5	...	...	...	...
8	Mineral Manure without Potash	...	...	3·5	...	*250	100	...
7	Complete Mineral Manure	...	...	3·5	500	100	100	...
6	As Plot 7; Ammonium-salts alone first 13 years	...	...	3·5	500	100	100	...
15	As Plot 7; Nitrate Soda alone first 18 years	...	...	3·5	500	100	100	...
5	Ammonium-salts alone (to 1897)	400	...	...	...	...	...	...
17	Nitrate of Soda alone	...	275	...	...	...	...	...
4-2	Superphosphate and Ammonium-salts	400	...	3·5	...	...	...	...
10	Mineral Manure (without Potash) and Ammonium-salts	400	...	3·5	...	*250	100	...
9	Complete Mineral Manure and Ammonium-salts	400	...	3·5	500	100	100	...
13	As Plot 9, and Chaffed Wheat Straw also to 1897	400	...	3·5	500	100	100	...
11-1	Complete Mineral Manure and Ammonium-salts	600	...	3·5	500	100	100	...
11-2	As Plot 11-1, and Silicate of Soda	600	...	3·5	500	100	100	400
16	Complete Mineral Manure and Nitrate Soda	...	275	3·5	500	100	100	...
14	Complete Mineral Manure and Nitrate Soda	...	550	3·5	500	100	100	...

* Reduced in 1905 to 100 lb.

B

C.—*Plan of the Plots in the Park on which Experiments have been made on the Mixed Herbage of Permanent Grass Land.*

1856 and onwards.



Total area under Experiment, about 7 acres.

Area of Plots:
- 1, 2, 3, 4-1, 4-2, 5-1, 5-2, 11-1, 11-2, and 12, each $\frac{1}{4}$ acre.
- 6, 7, 8, 9, 10, 13, and 18, each $\frac{1}{2}$ acre.
- 14, 15, 16, and 17, each $\frac{1}{6}$ acre.
- 19 and 20, each $\frac{1}{8}$ acre.

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TABLE XI.—*Produce of Hay per acre. Average over the period of* 47 *years* (1856-1902), *the* 10 *years* (1893-1902), *and the individual year* 1905. *Rothamsted. Total of first, and second crops (if any).*

Plot.	Abbreviated Description of Manures.	Averages over 47 years (1856-1902).	Averages over 10 years (1893-1902).	Season 1905.
		Cwt.	Cwt.	Cwt.
3	Unmanured every year	21·9	15·9	19·4
12	Unmanured every year	24·5	18·5	24·7
2	Unmanured; following Farmyard Dung for first 8 years	27·9*	17·4	23·2
1	Ammonium-salts alone (=43 lb. N.); with Farmyard Dung for first 8 years	35·4†	24·9	26·3
4-1	Superphosphate of Lime	23·3§	17·8	22·3
8	Mineral Manure without Potash	28·1	21·6	30·3
7	Complete Mineral Manure	38·8	36·5	52·9
6	Complete Mineral Manure as Plot 7; following Ammonium-salts alone first 13 years	37·4‡	36·0	46·1
15	Complete Mineral Manure as Plot 7; following Nitrate of Soda alone first 18 years	37·0‖	40·8	51·9
5	Ammonium-salts alone = 86 lb. Nitrogen	(26·1)**	...	...
17	Nitrate of Soda alone = 43 lb. Nitrogen	35·3¶	30·6	39·7
4-2	Superphosphate and Ammonium-salts = 86 lb. N.	35·5§	28·3	31·5
10	Mineral Manure (without Potash), and Ammonium-salts = 86 lb. N.	49·3	38·1	37·3
9	Complete Mineral Manure and Ammonium-salts = 86 lb. N.	54·1	46·8	48·6
13	As Plot 9, and Chaffed Wheat Straw also to 1897 inclusive	62·5**	...	...
11-1	Complete Mineral Manure, and Ammonium-salts = 129 lb. N.	65·5	64·6	59·0
11-2	As Plot 11-1, and Silicate of Soda	72·0	68·0	74·5
16	Complete Mineral Manure and Nitrate Soda = 43 lb. N.	48·0¶	42·4	52·3
14	Complete Mineral Manure and Nitrate Soda = 86 lb. N.	59·3¶	53·4	57·6

* After the change. Before the change, 42·9 cwt.
† " " 49·5 cwt.
‡ " " 30·6 cwt.
‖ " " 35·4 cwt.

§ 44 years only (1859-1902).
¶ 45 years only (1858-1902).
** 42 years (1856-1897).

The Unmanured Plots

Two of the plots have remained without manure during the whole of the experiment. They are situated near the extremities of the field, and show a slight but constant difference in crop. Taking the average of the whole period, these unmanured plots have produced rather more than a ton of hay per acre per annum. If we compare the successive ten-year returns, there is no sign of approaching exhaustion or great falling-off in crop from year to year. The impoverishment of these unmanured plots is more to be seen in the character of the herbage than in the gross weight of produce. Weeds of all descriptions occupy the land, and the relative proportion they bear to the grasses and clovers has increased from year to

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year. A fair proportion of clovers, both red and white, is found on these plots, but the weeds, which amount to 26 per cent. taking the average over the whole period, have of late years constituted nearly one-half of the herbage. The most prominent species among the grasses are the

TABLE XII.—*Percentages of Gramineous, Leguminous, and Miscellaneous Herbage. Average of* 47 *years* (1856-1902, *and* 1902 *separately*). *Rothamsted. First crops.*

Plot.	Manures.	Averages over 47 years (1856-1902).			Season 1902.		
		Gramineæ.	Leguminosæ.	Miscellaneæ.	Gramineæ.	Leguminosæ.	Miscellaneæ.
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
3	Unmanured every year	64·8	8·9	26·3	34·3	7·5	58·2
12	Unmanured every year	64·9	9·0	26·1	38·1	16·1	45·8
2	Unmanured; following Farmyard Dung for first 8 years	75·5	4·3	20·2	24·4	5·7	69·9
1	Ammonium-salts alone (=43 lb. N.); with Farmyard Dung for first 8 years	87·8	0·7	11·5	77·6	1·4	21·0
4-1	Superphosphate of Lime	68·0	5·8	26·2	54·4	15·4	30·2
8	Mineral Manure without Potash *	70·6	6·8	22·6	28·8	22·1	49·1
7	Complete Mineral Manure	62·0	23·8	14·2	20·3	55·3	24·4
6	Complete Mineral Manure as Plot 7; following Ammonium-salts alone first 13 yrs.	...	...	...	18·4	61·0	20·6
15	Complete Mineral Manure as Plot 7; following Nitrate of Soda alone first 18 years	...	...	...	26·2	63·1	10·7
5	Ammonium-salts alone = 86 lb. N.	80·5	0·4	19·1	...	...	...
17	Nitrate of Soda alone = 43 lb. N.	71·0	1·3	27·7	43·8	3·4	52·9
4-2	Superphosphate and Ammonium-salts = 86 lb. N.	88·2	0·1	11·7	91·5	(0·01)	8·5
10	Mineral Manure (without Potash),* and Ammonium-salts = 86 lb. N.	90·7	0·1	9·2	97·6	(0·01)	2·4
9	Complete Mineral Manure and Ammonium-salts = 86 lb. N.	88·7	0·4	10·9	91·2	1·3	7·5
13	As Plot 9, and Chaffed Wheat Straw also to 1897 inclusive	92·3	0·3	7·4	98·1	0·6	1·3
11-1	Complete Mineral Manure and Ammonium-salts = 129 lb. N.	95·8	0·1	4·1	99·2	0	0·8
11-2	As 11-1, and Silicate of Soda	97·5	0	2·5	99·5	0	0·5
16	Complete Mineral Manure and Nitrate Soda = 43 lb. N.	82·9	5·4	11·7	61·7	12·8	25·5
14	Complete Mineral Manure and Nitrate Soda = 86 lb. N.	90·6	1·3	8·1	88·8	3·7	7·5

* Including Potash first 6 years.

Quaking Grass, so generally taken as a sign of poor land, which constituted 20 per cent. of the whole herbage in 1903, and Sheep's Fescue; among leguminous plants the Bird's Foot Trefoil; and Burnet, Hawkbit, and Black Knapweed among the weeds.

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Use of Nitrogenous Manures alone

Three of the plots—17, 5, and 1—show the effect of the long-continued use of nitrogenous without any mineral manures, Plot 5 has been receiving 86 lbs. of nitrogen as ammonium-salts, Plot 17 half the quantity of nitrogen in the shape of nitrate of soda, and Plot 1 the same half quantity of nitrogen as ammonium-salts, though on this plot dung was applied in each of the first eight years of the experiment. It is very evident when a nitrogenous manure is used alone for grass, nitrate of soda is far more effective than the ammonium-salts; *e.g.*, on Plot 17 it has given an average crop of 35 cwt. against 26 cwt. produced by double the quantity of nitrogen in ammonium-salts on Plot 5.

Mineral Manures used alone

On three of the plots no nitrogenous manures have been applied since the beginning of the experiments. On Plot 7 a complete mineral manure,

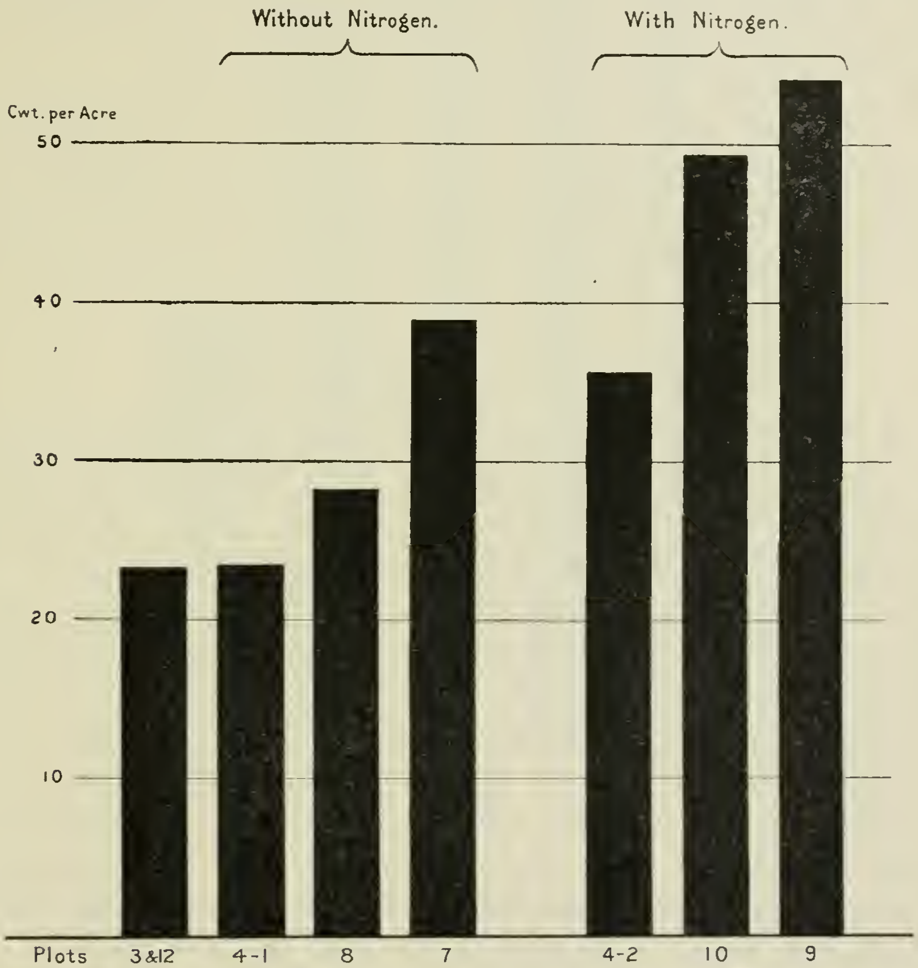

Fig. 6.—Effect of the various Ash constituents with and without Nitrogen on the produce of Hay per acre. Average over 47 years (1856-1902).

Plots 3 and 12. Unmanured.
Plot 4-1. Superphosphate.
Plot 8. Minerals with Potash.
Plot 7. Complete Mineral Manure.

Plot 4-2. Super. and Amm.-salts = 86 lb. N.
Plot 10. Minerals (without Potash) and Amm.-salts = 86 lb. N.
Plot 9. Complete Mineral Manure and Amm.-salts = 86 lb. N.

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supplying phosphoric acid, potash, magnesia, and soda, is used; Plot 8 has received the same application, but without potash, since 1861, while Plot 4-1 receives superphosphate only. With the complete minerals a fair crop is grown, averaging over 1½ ton of hay for the first cut alone. The reason that the crop on this plot is maintained, although no nitrogen is supplied in the manure, lies in the free growth of leguminous plants. It will be seen that, taking the average over the whole period, the leguminous plants form 24 per cent. of the herbage, and the proportion has increased from year to year.

The omission of potash on Plot 8 has caused a very striking difference both in the crop and in the character of the herbage. The average crop has been about one-quarter less over the whole period, and shows a progressive decline in fertility, until at the present time it is little more than half that of Plot 7. The poor results on this plot, as compared with Plot 7, must be put down to its poverty in leguminous herbage, the development of which seems to depend on a free supply of potash. Of late years the proportion of leguminous plants on this plot has amounted to about one-half of that found on Plot 7, the grasses are about the same, the difference being made up by an increased amount of weed.

Plot 4-1, which each year has received superphosphate only, now presents a very impoverished appearance, and is giving no more crop than the unmanured plots. Indeed, the aspect of this plot, where the most abundant grass is Quaking Grass, and where weeds, chiefly Hawkbit, Burnet, and Plantain, are unusually prominent, would seem to indicate that the land is more exhausted here than on the unmanured plot.

Complete Manures—Nitrogen and Minerals

Among the plots which receive both nitrogenous and mineral manures, Plot 9, with a complete mineral manure and ammonium-salts should be compared with Plot 14, which is exactly similar except that the nitrogen is applied in the form of nitrate of soda, and again with Plot 16, where only half the amount of nitrogen is applied, but again as nitrate of soda. The nitrate of soda gives the heavier yield, the herbage is also more diversified, and there is not the total absence of leguminous plants which marks the plots receiving ammonium-salts. Two characteristic plants, Soft Brome Grass and Beaked Parsley, are found only on the plots receiving nitrate of soda, the corresponding umbelliferous plant where ammonium-salts are used being the Earth Nut (Conopodium).

On Plot 11 the same mineral manures are applied with an extra amount of ammonium-salts, so that the nitrogenous manuring is excessive. As a result the vegetation consists entirely of tufts of three coarse grasses—Meadow Foxtail, Yorkshire Fog, and Tall Oat Grass. The soil has also become sour and unhealthy, with the result that the plant is dying in patches, except on the upper portion of the plot where lime has been applied, and on the half numbered 11-2 where the silicate of soda is used.

The effect of omitting potash from the complete manure is seen on Plot 10, and again on Plot 4-2, where superphosphate and ammonium-salts only are applied. It is noticeable that the grass on these plots is weak in the straw and liable to fungoid attacks.

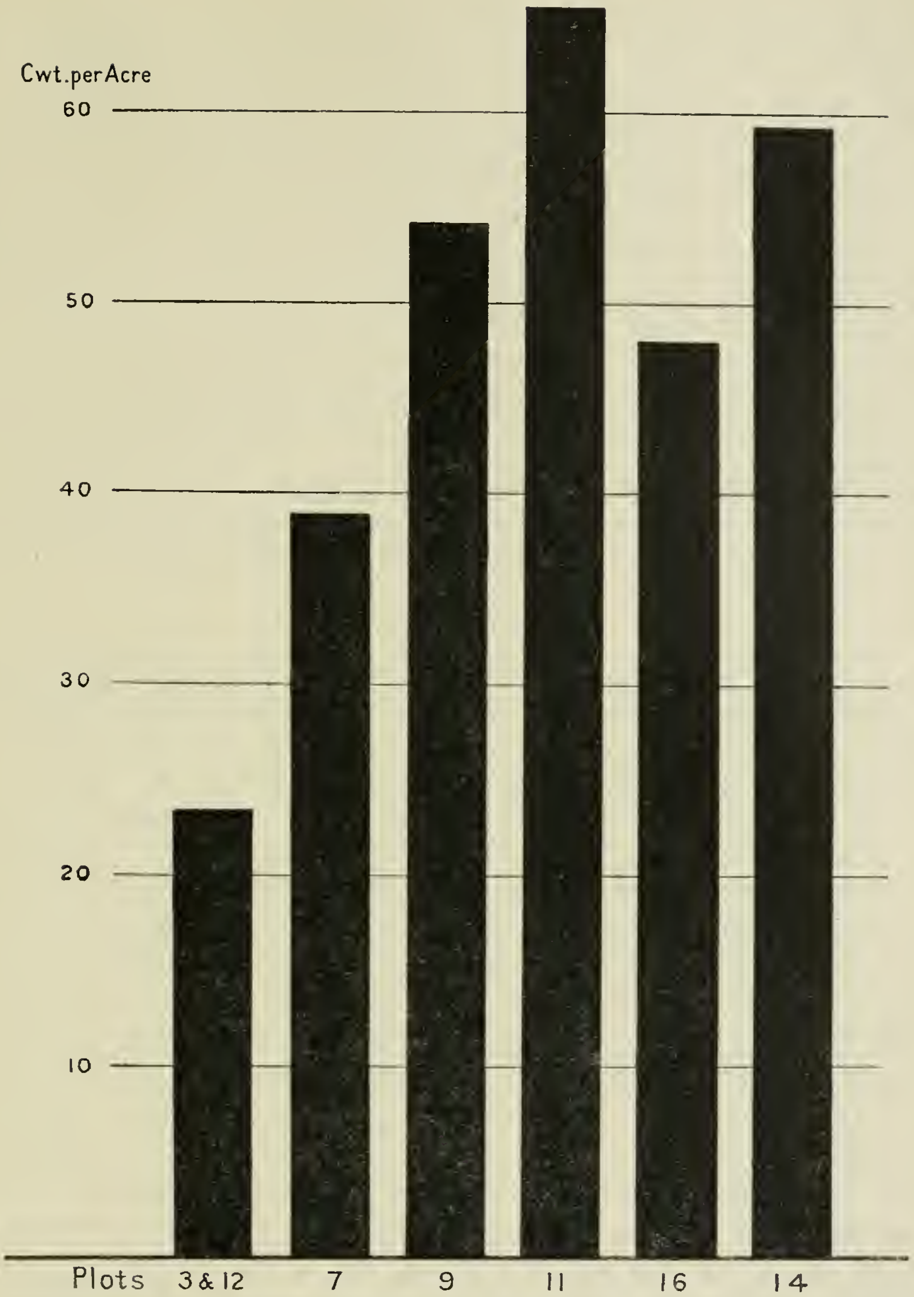

Fig. 7.—Effect of Nitrogenous Manures on the produce of Hay per acre. Average over 47 years (1856-1902).

Plot 3 and 12. Unmanured.
Plot 7. Complete Mineral Manure, no Nitrogen.
Plot 9. Do. and Amm.-salts = 86 lb. N.
Plot 11. Do. do. = 129 lb. N.
Plot 16. Do. and Nitrate of Soda = 43 lb. N.
Plot 14. Do. do. = 86 lb. N.

Changes in the Herbage following changes in Manuring

Plot 6 was up to 1868 manured with ammonium-salts alone, like the adjoining Plot 5: the ammonium-salts were then replaced by a complete mineral manure containing potash. The result is seen in the way leguminous plants have gradually invaded the plot until they now predominate as they do on Plot 7, where mineral manures have been used throughout. The southern half of Plot 5 has also been manured with minerals instead of ammonium-salts since 1898, and the gradual invasion of leguminous plants may now be seen in progress. The northern half of Plot 5 has been unmanured since 1898, when the ammonium-salts were discontinued.

On Plot 15 nitrate of soda was applied up to 1875, when a change to a complete mineral manure was made, with the same result of the incoming of the leguminous plants.

The southern halves of Plots 1 to 4-2, 7 to 11-2, 13 and 16 were dressed with ground quick-lime at the rate of 2000 lb. per acre in January 1903, and changes in the herbage resulting therefrom are now in progress.

Plot 18, which, up to 1905, was in an impoverished condition, has since been receiving a complete manure except for the omission of any phosphoric acid.

Use of Dung

Three plots were selected in 1905 to illustrate the effects of dung applied occasionally, either alone or in combination with artificial manures, as follows :—

Plot 19. 14 tons Dung 1905, and every fourth year.
Unmanured intervening years.

Plot 20. 14 tons Dung 1905, and every fourth year.
1½ cwt. Nitrate of Soda, 200 lb. Superphosphate, 100 lb. Sulphate of Potash — Every intervening year.

Plot 13. 14 tons Dung 1905, and every fourth year.
6 cwt. Fish Guano 1907, and every fourth year.

BROADBALK FIELD—WHEAT

The experiments on the continuous growth of wheat were begun in the Broadbalk field in 1843, but for the first eight years the manuring was of a varied description, so that only three of the plots have received the same treatment during the whole period of sixty years. The plots as seen to-day began in 1852, since which time the few changes in manuring have been matters of detail and not of principle.

The chief difficulty experienced in growing wheat continuously is that of keeping the land clean; not only does the crop occupy the ground for the greater part of the year, and so leave little opportunity for cleaning operations, but the weeds whose habit of growth is favoured by the crop tend to accumulate from year to year. Thus in spite of repeated hand-hoeings, some weeds, like the "Black Bent" grass, *Alopecurus agrestis*, are kept under with the greatest difficulty.

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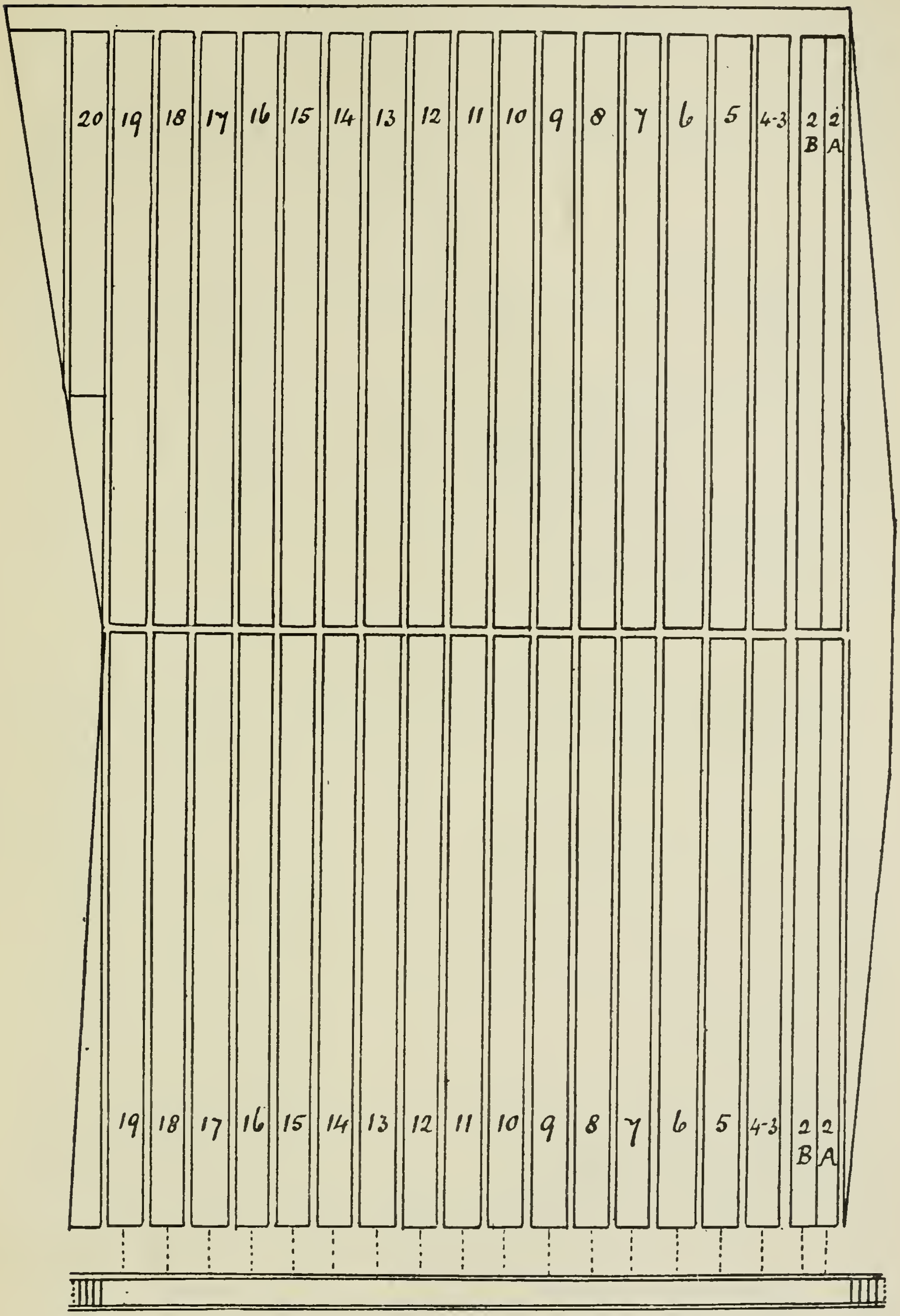
D.—*Plan of the Plots in Broadbalk Field, on which Wheat has been grown since* 1843-4.



Brick Trench for collecting the Pipe Drainage from each Plot.

Total area of ploughed land about 11 acres.
Area of Plots 3-4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, and 19, each $\frac{1}{2}$ acre.
Area of Lands A and B of Plot 2, each $\frac{3}{10}$ acre.
Area of Plot 20, about $\frac{1}{8}$ acre.
The double lines indicate division paths between plot and plot; also a path across the centre of each plot.

TABLE XIII.—*Experiments on Wheat, Broadbalk Field. Manuring of the Plots per acre per annum,* 1852 *and since.*

Plot.	Abbreviated Description of Manuring.	Nitrogenous Manures.				Mineral Manures.			
		Farmyard Manure.	Rape Cake.	Nitrate of Soda.	Ammonium-salts.	Super-phosphate.	Sulphate of Potash.	Sulphate of Soda.	Sulphate of Magnesia.
		Tons.	Lb.	Lb.	Lb.	Cwt.	Lb.	Lb.	Lb.
2	Farmyard Manure	14	...	...	...	...	...	...	...
3	Unmanured	...	...	...	...	...	...	...	...
5	Minerals	...	...	...	...	3·5	200	100	100
6	Single Ammonium-salts and Minerals	...	...	...	200	3·5	200	100	100
7	Double do. do.	...	...	...	400	3·5	200	100	100
8	Treble do. do.	...	...	...	600	3·5	200	100	100
9	Single Nitrate and Minerals	...	...	275	...	3·5	200	100	100
10	Double Ammonium-salts alone	...	...	...	400	...	...	...	...
11	Do. and Superphosphate	...	...	...	400	3·5	...	...	...
12	Do. do. and Sulph. Soda	...	...	...	400	3·5	...	366·5	...
13	Do. do. and Sulph. Potash	...	...	...	400	3·5	200	...	...
14	Do. do. and Sulph. Mag.	...	...	...	400	3·5	...	...	280
15	Double Amm.-salts in autumn, and Minerals	...	...	...	400	3·5	200	100	100
16	Double Nitrate and Minerals	...	...	550	...	3·5	200	100	100
17	Minerals alone, or Double Amm.-salts	...	...	...	...	3·5	200	100	100
18	alone, in alternate years	...	...	...	400	...	...	...	...
19	Rape Cake alone	...	1889	...	...	...	...	...	...

TABLE XIV.—*Experiments on Wheat, Broadbalk Field. Produce of Grain and Straw per acre. Average over* 51 *years* (1852-1902); *and over* 10 *years* (1893-1902); *also Produce in* 1905.

Plot.	Abbreviated Description of Manuring.	Dressed Grain.			Straw.		
		Average, 51 years (1852-1902).	Average last 10 years (1893-1902).	Season 1905.	Average, 51 years (1852-1902).	Average last 10 years (1893-1902).	Season 1905.
		Bush.	Bush.	Bush.	Cwt.	Cwt.	Cwt.
2	Farmyard Manure	35·7	40·0	38·5	34·1	40·4	51·3
3	Unmanured	13·1	12·7	18·0	10·5	9·3	19·7
5	Minerals	14·9	15·4	24·0	12·2	11·8	24·6
6	Single Ammonium-salts and Minerals	24·0	23·5	32·3	21·5	20·2	38·2
7	Double do. do.	32·9	32·4	40·7	33·0	32·2	46·7
8	Treble do. do.	37·1	39·2	40·5	40·9	43·0	51·3
9	Single Nitrate and Minerals	...	27·3	36·7	...	25·5	41·4
10	Double Ammonium-salts alone	20·7	19·6	16·7	18·7	16·7	20·7
11	Do. and Superphosphate	24·0	20·2	18·9	22·7	19·2	27·7
12	Do. do. and Sulph. Soda	30·0	27·6	30·5	28·3	25·2	36·7
13	Do. do. and Sulph. Potash	31·5	30·6	39·4	31·3	29·8	44·4
14	Do. do. and Sulph. Mag.	30·1	25·9	26·0	28·8	24·0	30·1
15	Double Amm.-salts in autumn, and Minerals	30·6	28·2	37·5	29·8	27·5	42·0
16	Double Nitrate and Minerals	...	32·5	34·2	...	33·3	46·6
17	Minerals alone, or Double Ammonium-salts *	15·3	15·9	25·6	13·1	12·8	27·1
18	alone, in alternate years †	30·4	30·0	31·5	29·5	29·0	35·8
19	Rape Cake alone	...	28·0	22·7	...	26·7	30·1

* Produce by Minerals. † Produce by Ammonium-salts.

On Plot 3 wheat has been grown without manure every year since 1843, for four years previously no manure had been applied to the field, so that the present crop is the sixty-seventh without manure After a drop in production during the first few years, the yield has been practically constant for the last forty years, fluctuating only with the season, and showing no immediate prospect of declining. The average crop over this period has amounted to about 12½ bushels per acre, approximately equal to the average yield, taking the whole world over.

Effect of Nitrogenous Manures

Plots 6, 7, and 8 should be compared with Plot 5, since all receive the same mineral manures, but different amounts of nitrogen as ammonium-salts.

Plot 5, which receives the minerals but no nitrogen, grows very little more than the continuously unmanured plot; its average over the whole period is only 14·9 bushels, as against 13·1 without manure of any description. The yield of the other three plots increases with each addition of nitrogen; the grain increases from 24 bushels with 43 lb. of nitrogen, to 33 bushels with 86 lb. of nitrogen, and to 37 bushels with 129 lb. of nitrogen; the straw is even more affected by a free supply of nitrogen, rising from 21½ cwt. to 33 and 41 cwt. as the nitrogen is doubled and trebled.

Comparative Effect of Nitrate of Soda and Ammonium-salts

Plot 6 should be compared with Plot 9, and Plot 7 with Plot 16. Plots 9 and 16 receive nitrate of soda and mineral manures, so that Plot 9 has the same manuring as Plot 6, and Plot 16 as Plot 7, except that the ammonium-salts on Plots 6 and 7 are replaced by equivalent amounts of nitrate of soda. The manuring of Plots 9 and 16 has, however, been changed during the progress of the experiments, so that they are only comparable with 6 and 7 since 1885. Taking the averages of the last ten years, as set out in the diagram Fig. 9, it will be seen that nitrate of soda is a more effective source of nitrogen than the ammonium-salts; the single application yields 16 per cent. more grain and 26 per cent. more straw than the corresponding amount of ammonium-salts; the double application, however, yields practically the same amount of grain, and only about 1 cwt. more straw.

Effect of the Mineral Constituents

The series of Plots 7, 10, 11, 12, 13, and 14 all receive the same amount of nitrogen—86 lb., in the form of 400 lb. of ammonium-salts per acre—but differ in regard to their mineral manuring. Plot 10 receives nothing beyond the nitrogen, Plot 11 has superphosphate also, while 12, 13, and 14 receive a further addition of sulphate of soda, sulphate of potash, or sulphate of magnesia respectively, all three of which are combined to form a complete mineral manure on Plot 7.

Retention of Manures by the Soil

As a rule 100 lb. of the ammonium-salts are applied in the autumn when the seed is sown, the rest being reserved for a top-dressing in the spring. On one of the plots, however, Plot 15, the whole 400 lb. of

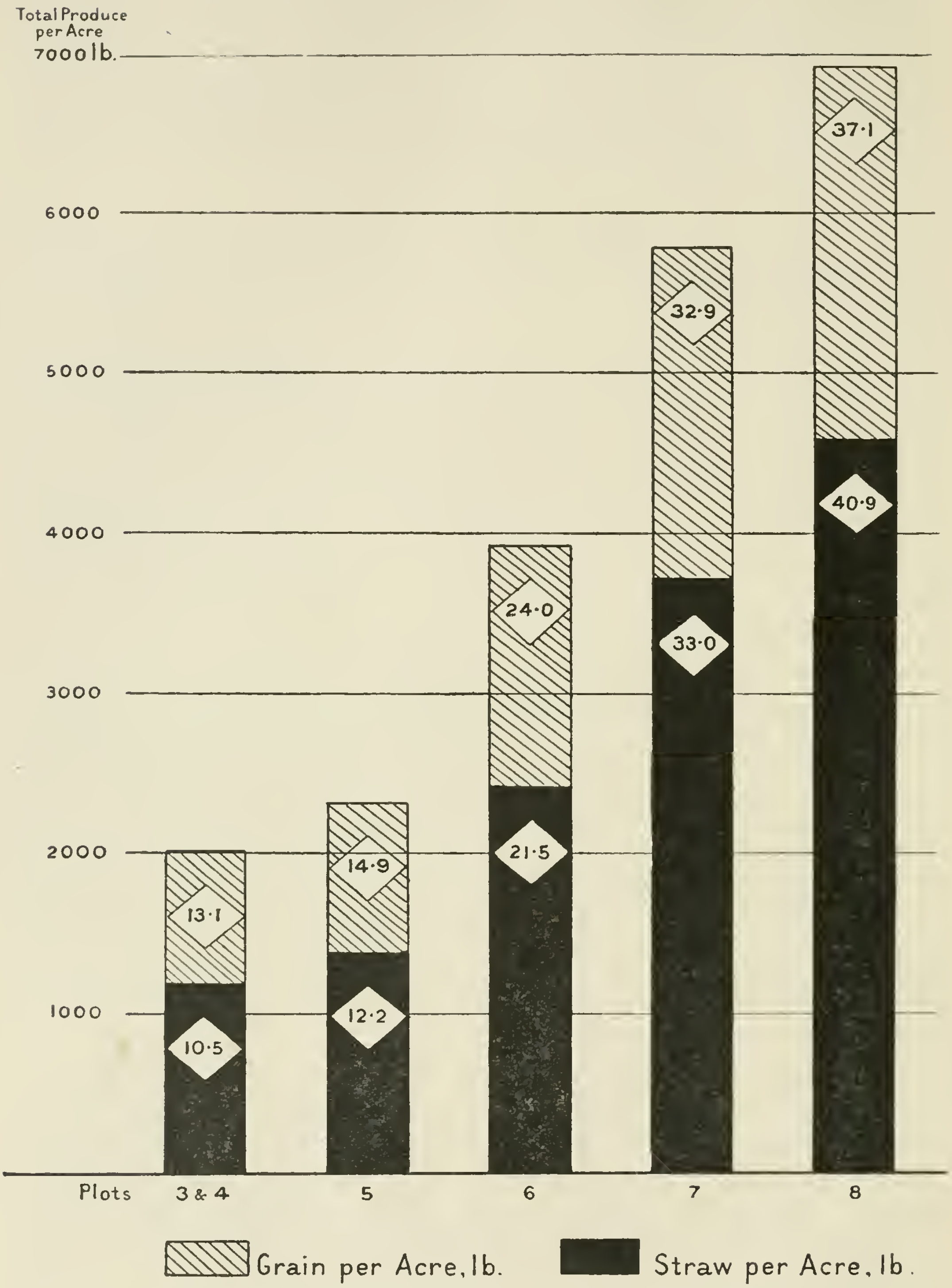


FIG. 8.—Broadbalk Wheat. Effect of increasing amounts of Nitrogen on the production of Wheat (Grain and Straw). Average, 51 years (1852-1902).

The figures in the labels indicate bushels of Grain and cwt. of Straw.

ammonium-salts is applied in the autumn, otherwise the manuring is identical with that of Plot 7. The crop, however, on Plot 15 is on the average below that of Plot 7, showing that some loss takes place when the ammonium-salts are applied before the plant is able to utilise them. Plots 17 and 18 further illustrate the fate of ammonium-salts. These plots receive the dressing of Plot 7—400 lb. ammonium-salts and complete minerals—but the ammonium-salts and the minerals are applied in alternate years to the two plots. Thus in 1906 Plot 17 receives ammonium-salts but no minerals, and Plot 18 the minerals without the ammonium-salts, and the treatment is reversed in 1905 and again in 1907. The plot which in any year is receiving minerals without nitrogen derives

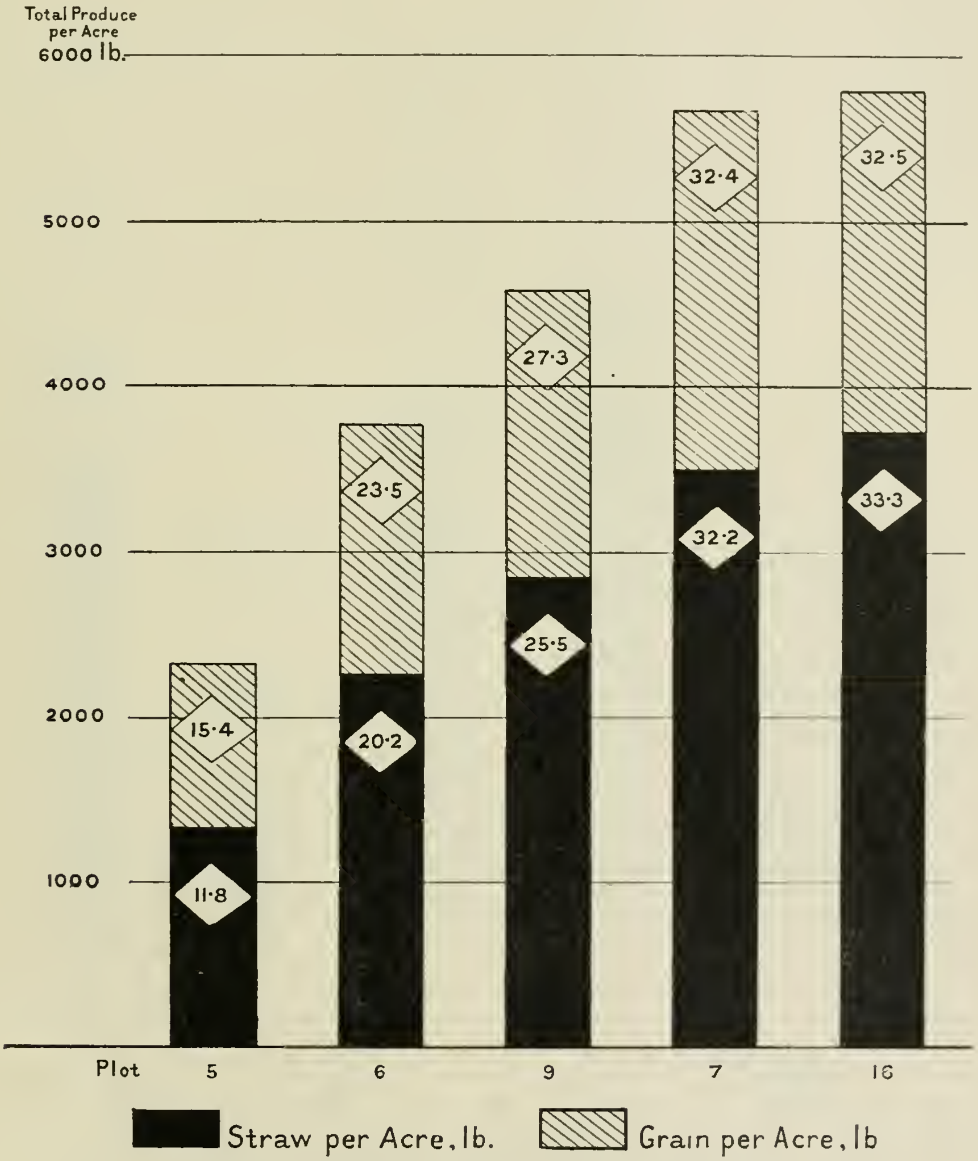


FIG. 9.—Comparison of Nitrate of Soda and Ammonium-salts on Wheat. Ten years (1893-1902). All Plots receive Minerals alike.
The figures in the labels indicate bushels of Grain and cwt. of Straw.

little or no benefit from the ammonia it had the year before. The crop shows every sign of nitrogen starvation, and amounts on the average to only 15·3 bushels of grain, as compared with 14·9 bushels on Plot 5 which has received minerals without any nitrogen every year since 1852. On the Rothamsted soil, then, we may conclude that the effect of sulphate of ammonia applied to a cereal crop is confined to the season of its application. In the seasons when the ammonium-salts are applied the crop is but little

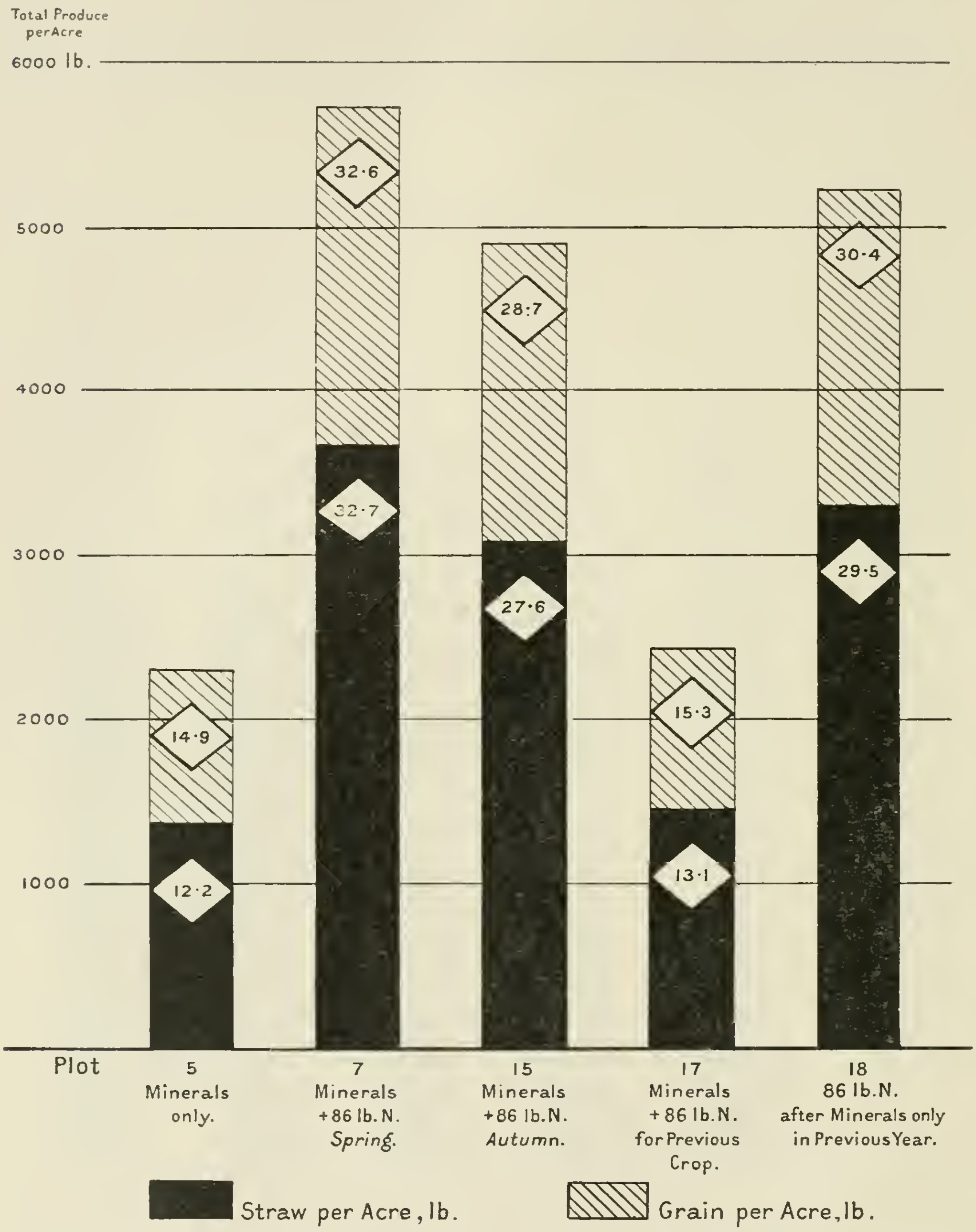


FIG. 10.—Comparative Effects on Wheat of Ammonium-salts applied at different times.

Averages—Plots 5, 17, and 18, 51 years (1852-1902).
Plots 7 and 15, 25 years only (1878-1902).

The figures in the labels indicate bushels of Grain and cwt. of Straw.

short of that on Plot 7, where minerals are used every year with the same amount of ammonium-salts, thus showing that the previous mineral manuring is carried forward and has an effect in seasons beyond the year of its application.

HOOS FIELD—BARLEY

The experiments on the continuous growth of barley were begun in the Hoos field in 1852. The arrangement of the plots and the manures applied to each plot have practically been unchanged since, so that the plots to-day show the effects of more than fifty years' continuous growth of barley under the same treatment year after year. There are four longitudinal strips receiving different combinations of the mineral manures; these are all crossed by four breadths receiving different nitrogenous manures. The mineral manuring on the strips is as follows:—(1) None; (2) Phosphoric acid only, no potash or alkali salts; (3) Potash, magnesia, and soda, no phosphoric acid; and (4) Complete mineral manure, supplying both phosphoric acid and the alkaline salts. Each of these is combined with the four cross-dressings of nitrogenous manures—Series O, no nitrogen; Series A, ammonium-salts; Series N, nitrate of soda; and Series C, rape cake. There are other plots, one of which has received farmyard manure for the first twenty years, but has since been unmanured.

Table XV.—*Experiments on Barley, Hoos Field. Manuring of the Plots per acre per annum,* 1852 *and since.*

Plot.	Abbreviated Description of Manures.	Nitrogenous Manures.				Mineral Manures.			
		Farmyard Manure.	Rape Cake.	Ammonium-salts.	Nitrate of Soda.	Super-phosphate.	Sulphate of Potash.	Sulphate of Soda.	Sulphate of Magnesia.
		Tons.	Lb.	Lb.	Lb.	Cwt.	Lb.	Lb.	Lb.
1 O	No Minerals, and no Nitrogen	...	...	...	...	...	...	...	...
2 O	Superphosphate only, do.	...	...	...	...	3·5	...	...	...
3 O	Alkali Salts only, do.	...	...	...	...	...	200	100	100
4 O	Complete Minerals, do.	...	...	...	...	3·5	200	100	100
1 A	Ammonium-salts alone	...	...	200	...	...	...	...	...
2 A	Superphosphate and Ammonium-salts	...	...	200	...	3·5	...	...	...
3 A	Alkali Salts and do.	...	...	200	...	...	200	100	100
4 A	Complete Minerals and do.	...	...	200	...	3·5	200	100	100
1 N	Nitrate of Soda alone	...	...	...	275	...	...	...	...
2 N	Superphosphate and Nitrate of Soda	...	...	...	275	3·5	...	...	...
3 N	Alkali Salts and do.	...	...	...	275	...	200	100	100
4 N	Complete Minerals and do.	...	...	...	275	3·5	200	100	100
1 C	Rape Cake alone	...	1000	...	...	...	...	...	...
2 C	Superphosphate and Rape Cake	...	1000	...	...	3·5	...	...	...
3 C	Alkali Salts and do.	...	1000	...	...	...	200	100	100
4 C	Complete Minerals and do.	...	1000	...	...	3·5	200	100	100
7-1	Unmanured (after dung 20 yrs., 1852-71)	...	...	...	...	...	...	...	...
7-2	Farmyard Manure	14	...	...	...	...	...	...	...

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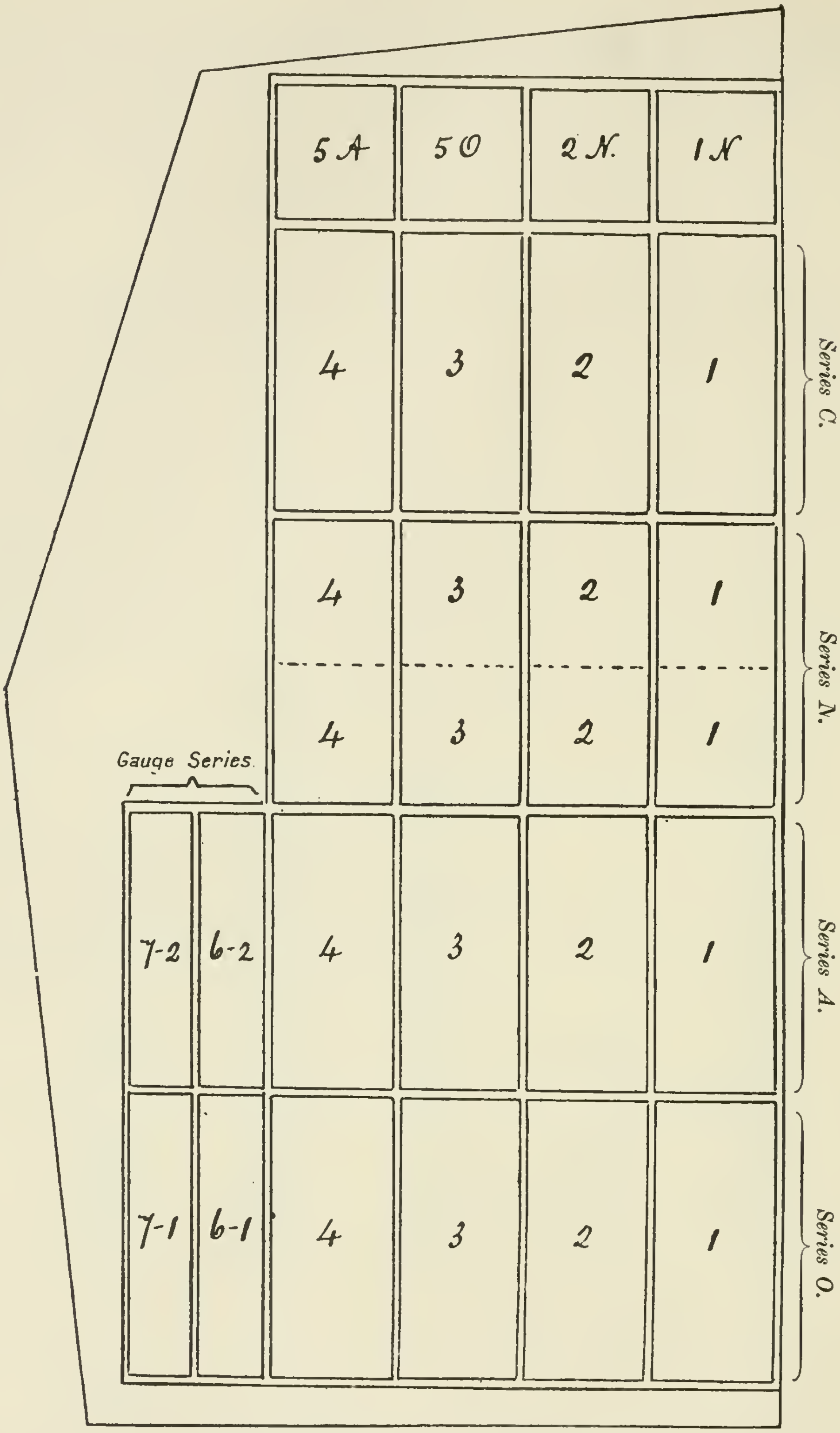
E.—*Plan of the Plots in Hoos Field, on which Barley has been Grown since* 1852.



Total area of ploughed land about $5\frac{1}{2}$ acres.

Area of Plots.
- 1, 2, 3, and 4, of Series O, Series A, and Series C, each $\frac{2}{11}$ acre.
- 1, 2, 3, and 4, of Series N, each $\frac{2}{11}$ acre.
- 1 N, 2 N, 5 O, and 5 A, each $\frac{1}{11}$ acre.
- 6-1 and 6-2, each about $\frac{1}{7}$ acre.
- 7-1 and 7-2, each about $\frac{1}{9}$ acre.

The double lines indicate division paths between plot and plot.

TABLE XVI.—*Experiments on Barley, Hoos Field. Produce of Grain and Straw per acre. Averages over* 51 *years* (1852-1902), *and over* 10 (1893-1902). *Also Produce in* 1905.

Plot.	Abbreviated Description of Manures.	Dressed Grain.			Straw.		
		Average, 51 years (1852-1902).	Average, 10 years (1893-1902).	Season 1905.	Average, 51 years (1852-1902).	Average, 10 years (1893-1902).	Season 1905.
		Bush.	Bush.	Bush.	Cwt.	Cwt.	Cwt.
1 O	No Minerals, and no Nitrogen . .	15·3	10·1	6·5	8·8	6·4	5·3
2 O	Superphosphate only, do. . .	20·1	13·6	11·9	10·2	7·8	6·7
3 O	Alkali Salts only, do. . .	16·1	8·9	7·7	8·9	5·9	7·0
4 O	Complete Minerals do. . .	20·4	12·4	16·8	10·8	8·0	11·9
1 A	Ammonium-salts alone . . .	26·5	16·2	12·3	14·9	10·5	11·9
2 A	Superphosphate and Ammonium-salts .	39·9	26·8	22·1	22·5	16·5	19·0
3 A	Alkali Salts and do. .	29·4	20·8	14·9	17·0	12·9	14·0
4 A	Complete Minerals and do. .	42·1	35·1	35·5	24·9	20·5	22·2
1 N	Nitrate of Soda alone	30·4	20·5	17·3	18·1	14·4	14·3
2 N	Superphosphate and Nitrate of Soda .	44·0	35·9	32·9	26·2	23·0	25·8
3 N	Alkali Salts and do. .	31·5	23·4	17·3	19·7	15·3	14·8
4 N	Complete Minerals and do. .	43·5	34·9	32·2	27·4	22·6	24·7
1 C	Rape Cake alone	39·2	31·0	29·0	22·4	18·4	17·1
2 C	Superphosphate and Rape Cake . .	41·5	33·2	28·5	23·9	19·6	17·7
3 C	Alkali Salts and do. . .	37·7	29·6	29·3	22·4	18·1	20·8
4 C	Complete Minerals and do. . .	41·0	32·5	34·2	24·5	20·1	23·1
7-1	Unmanured (after dung 20 yrs., 1852-71)	27·0*	19·9	14·1	15·4*	12·8	8·6
7-2	Farmyard Manure	47·6	42·6	39·4	29·1	28·8	27·9

* Average 31 years (1872-1902).

Effect of Nitrogenous Manures

The effect of nitrogenous manures upon the barley crop is best seen by comparing the yields of the various Plots 4, all of which receive the same mineral manures ; the diagram, Fig. 11, shows this comparison in a graphic form.

Effect of Mineral Manures

The diagram, Fig 12, shows in a graphic form the effects of the various mineral manures, the nitrogen supply being the same in all cases.

The great importance of phosphoric acid to the barley crop is seen on comparing Plots 3 and 4, which only differ from one another in the omission of phosphoric acid on Plot 3. In the field the most striking effect is seen in the hastened maturity brought about by the phosphoric acid. By comparing Plot 2 with Plot 4 we can see the effect of omitting potash from the manure. Where nitrate of soda is used as the source of nitrogen the soda liberates sufficient potash from the soil to supply the needs of the crop, but with ammonium-salts the omission of potash has latterly begun to tell upon the yield, though it did not do so in the earlier years of the experiment.

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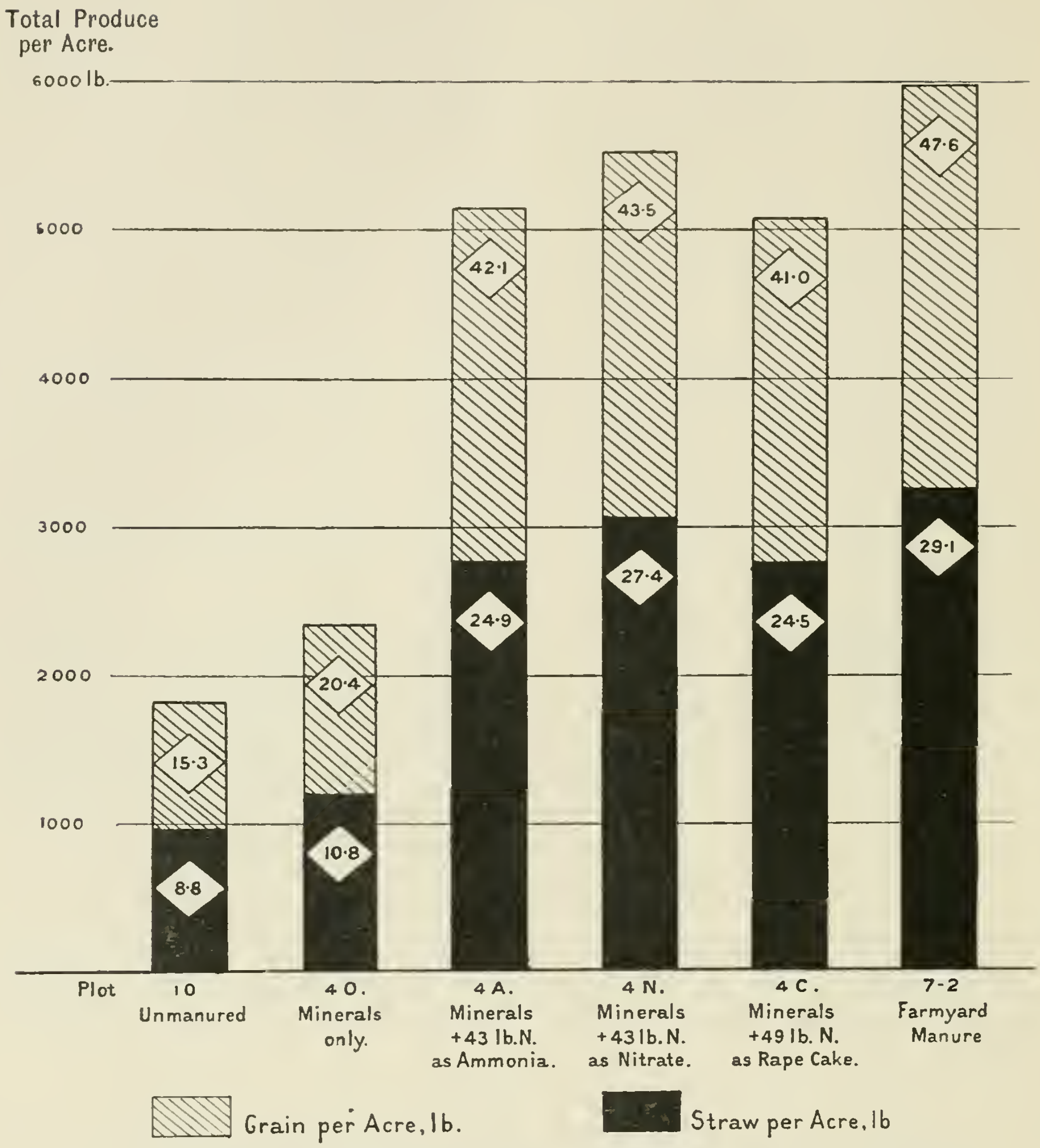


FIG. 11.—Yield in Barley (Grain and Straw) with different sources of Nitrogen. Averages for 51 years (1852-1902).

The figures in the labels indicate bushels of Grain and cwt. of Straw.

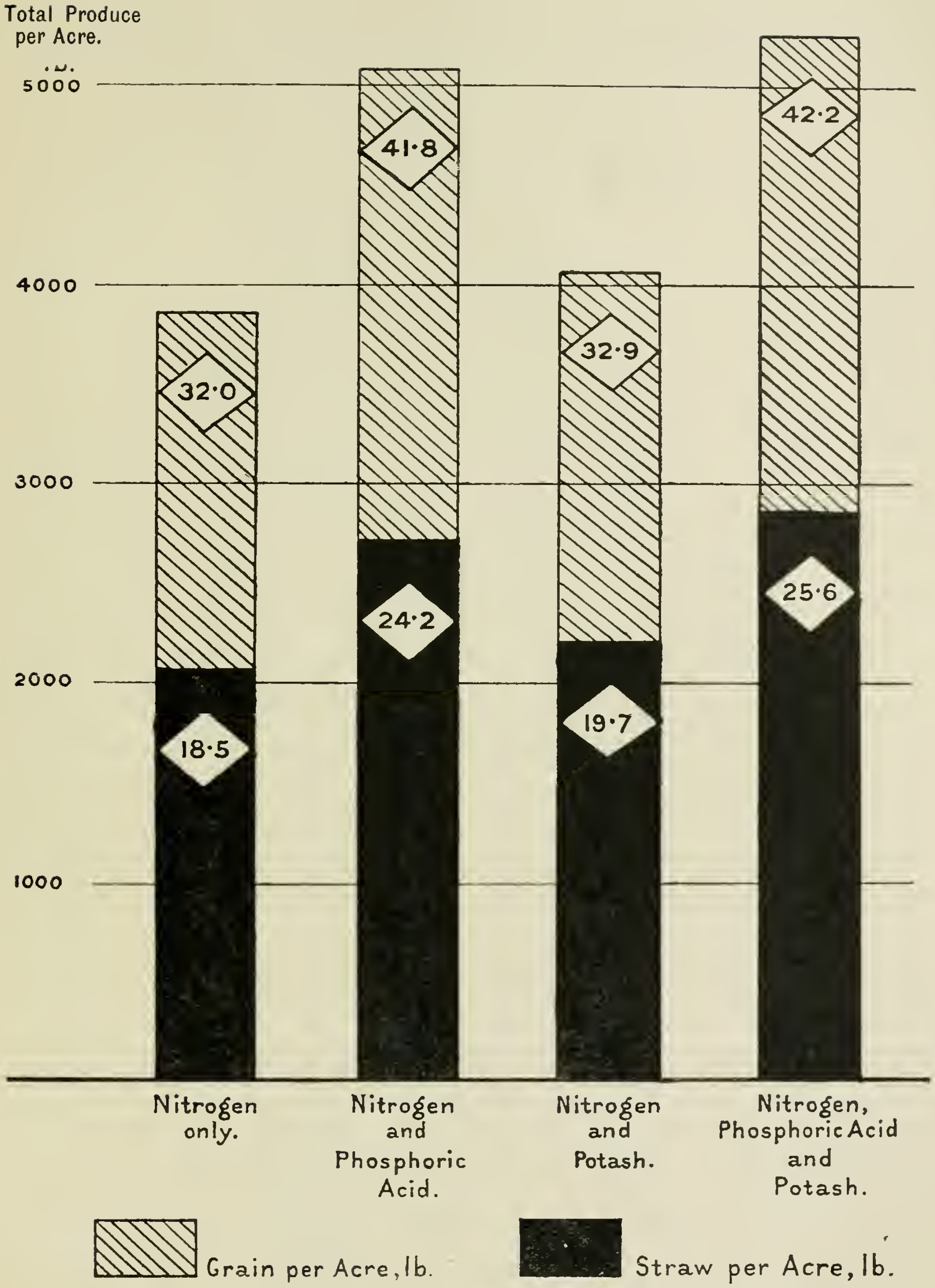
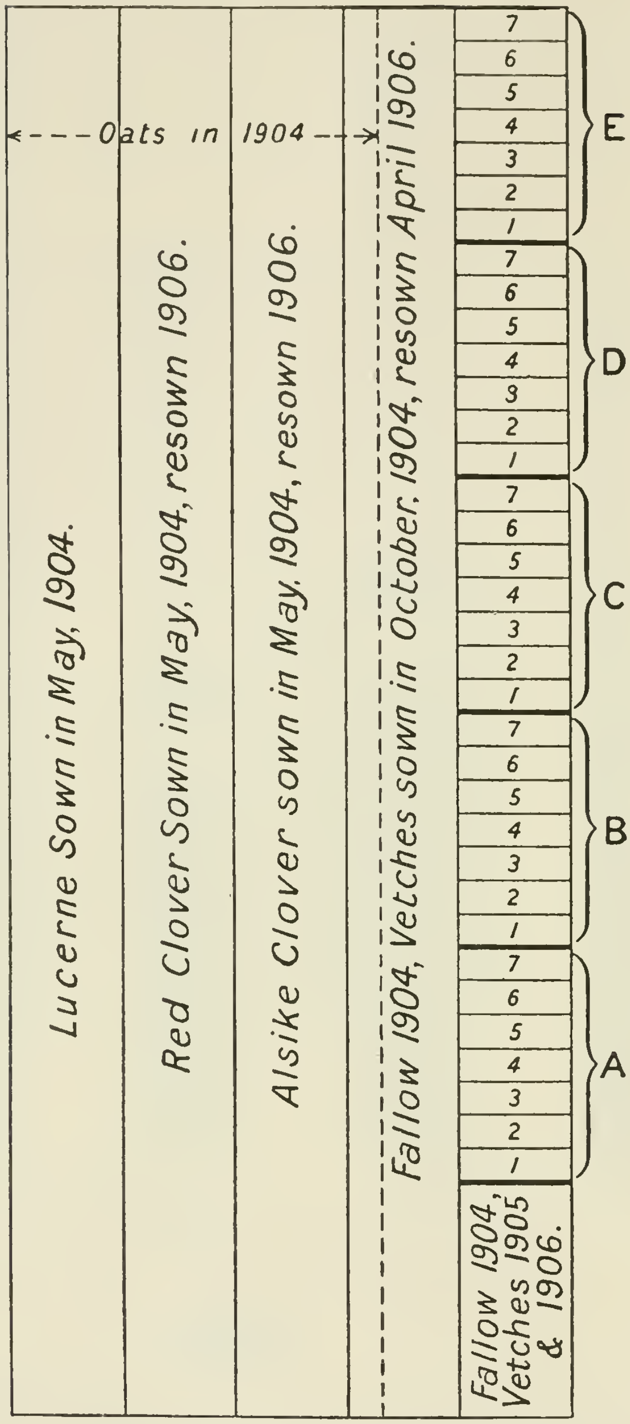


FIG. 12.—Effect of Mineral Manures on the yield of Barley (Grain and Straw). Mean of Series A. N. and C. 51 years (1852-1902).
The figures in the labels indicate bushels of Grain and cwt. of Straw.

F.—*Hoos Field Leguminous Plots. Season* 1906.

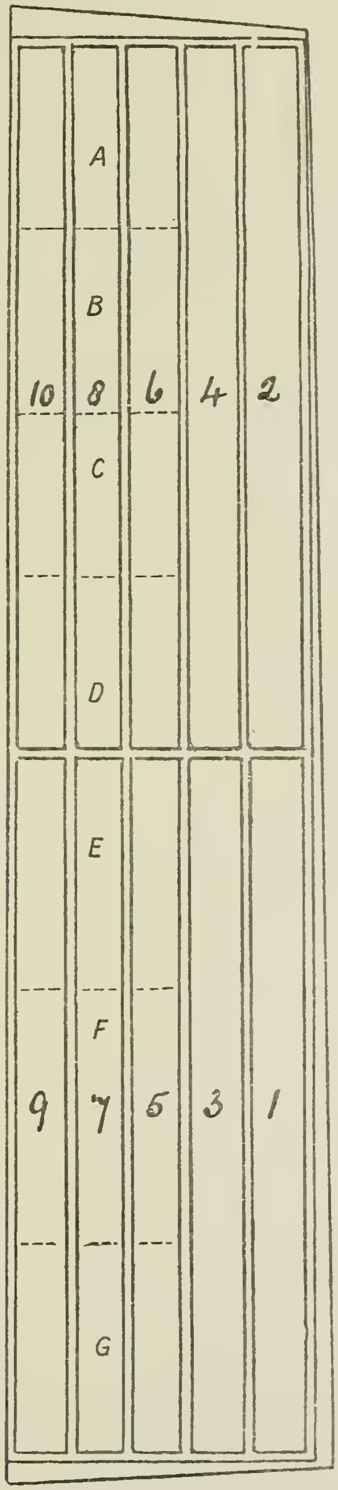


[Total area under experiment about 3 acres.]

G.—*Plan of the Plots in Hoos Field, on which Potatoes were grown without Manure, and with various Manures.*

26 years, 1876-1901.

In 1902 and 1903 Barley, and in 1904 Oats, were sown, without manure, to determine the duration of the residues of the previous manuring. In 1905 Barley was again sown on Plots 1-4 without manure. Plots 5-10 sown with Leguminous seeds.



Total area of ploughed land about $2\frac{1}{16}$ acres. Area of each plot $\frac{1}{8}$ acre.
The double lines indicate division paths between plot and plot.

c 2

HOOS FIELD LEGUMINOUS PLOTS

1848-9 onwards

The small plots (see Plan on page 36) represent portions of the original plots on which attempts have been made to grow leguminous plants continuously since 1848. Various combinations of mineral manures have been used up till 1898, but after the first few years very small crops have been grown, and the clovers in particular generally fail. After fallowing in 1903 to clean the plots, they were resown as before in 1904.

The remainder of the area was formerly occupied by similar small plots of the same leguminous plants. These were ploughed up in 1898, and five crops of wheat were taken without manure in order to test the amount of nitrogen accumulated by the leguminous crop and left in the soil.

In 1904 black tartarian oats were sown, and in the oats, lucerne, red clover, and alsike clover were sown on three strips; a fourth strip, fallowed in 1904, was sown with vetches in October of that year, as shown in the Plan on page 36. The new plots run across the old ones at right angles. The following table shows the crop obtained in 1905, after which the clover and vetch plots were broken up and resown in a barley crop in 1906.

Table XVII.—*Produce per acre, as Hay. Season* 1905.

	First Crop.	Second Crop.	Total.
	Cwt.	Cwt.	Cwt.
Lucerne . . .	21·5	16·6	38·1
Red Clover . .	25·7	21·5	47·2
Alsike Clover . .	36·9	...	36·9
Vetches . . .	45·8	...	45·8

HOOS FIELD—POTATO PLOTS

Residue of Manures

On ten plots potatoes were grown with various manures for 26 years (1876-1901), with the results set out in Table XVIII. In 1902 the manuring was discontinued and barley sown; this was again followed by barley in 1903, and by oats in 1904. The yield produced by the residues of the manures applied to the potatoes is shown in Table XVIII.

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HOOS FIELD

TABLE XVIII.—*Produce of Barley per acre in* 1902 *and* 1903, *without Manure, on the Plots which had grown Potatoes, variously Manured, in the* 26 *years*, 1876-1901, *inclusive. In* 1904 *Black Tartarian Oats were sown, again without Manure.*

Plot.	Potatoes, 1876-1901. Manures per acre per annum. (In the 5 years, 1897 to 1901, 400 lb. Basic Slag was used throughout instead of Superphosphate.)	Potatoes, 1876-1901. Average Produce of Total Tubers per acre.	Barley, Unmanured. 1902. Dressed Grain.	Barley, Unmanured. 1902. Total Straw.	Barley, Unmanured. 1903. Dressed Grain.	Barley, Unmanured. 1903. Total Straw.	Oats, Unmanured. 1904. Dressed Grain.	Oats, Unmanured. 1904. Total Straw.
		Tons.	Bush.	Lb.	Bush.	Lb.	Bush.	Lb.
1	Unmanured, 1876 and since	1·4	33·2	1799	9·6	544	23·1	1346
2	Unmanured, 1882 and since. Previously Farmyard Manure, 14 tons	2·8	35·4	1872	15·2	1020	21·5	1176
3	Farmyard Manure, 14 tons, 1883 and since. Previously Superhosphate also	4·8	71·0	5216	46·9	3474	55·5	3060
4	Farmyard Manure, 14 tons, 1883 and since, 1882 and previously Superphos., and in 1881 and previously Nitrate Soda = 86 lb. Nitrogen also	5·1	72·4	5115	44·9	3486	61·5	3258
5	Ammonium-salts = 86 lb. Nitrogen	1·7	59·1	3774	19·2	1018	24·1	1170
6	Nitrate Soda = 86 lb. Nitrogen	2·1	62·9	4275	18·6	911	22·7	1263
7	Ammonium-salts = 86 lb. Nitrogen, and Mixed Mineral Manure*	5·3	64·4	4286	28·9	1634	30·9	1693
8	Nitrate Soda = 86 lb. Nitrogen, and Mixed Mineral Manure	5·4	67·0	4629	26·2	1748	32·6	1635
9	Superphosphate only	2·7	35·1	1811	13·3	890	22·7	1104
10	Mixed Mineral Manure only	2·9	24·8	1610	12·8	887	20·6	1151

* "Mixed Mineral Manure," Superphosphate, and Sulphates of Potash, Soda and Magnesia.

On Plots 1, 2, 3, and 4 barley was again sown (without manure) in 1905, and gave the following results:—

TABLE XIX.—*Produce per acre in* 1905.

Plot.	Dressed Grain.		Straw.	Total Produce.
	Yield.	Weight per Bushel.		
	Bush.	Lb.	Cwt.	Lb.
1	4·6	52·0	3·0	613
2	7·1	52·3	3·4	799
3	28·3	55·7	14·8	3317
4	30·3	55·9	17·2	3693

HOOS FIELD

INOCULATION OF LEGUMINOUS PLANTS

Since the land on which potatoes had been formerly grown (see Plan on page 37) is known to have carried no leguminous crop for the last fifty years, it was decided to use those plots which no longer showed much residue of the manures previously applied, *i.e.*, Plots 5-10, for testing the comparative effects of different media for inoculating leguminous plants with their appropriate bacteria. Plots 6, 8, and 10 were divided transversely into four plots; on A, soil inoculated with Hiltner's preparation from Munich; on B, soil inoculated with Moore's preparation from the United States; on C, soil from a field which had carried red clover in 1904, were sown on 7th April; D being left uninoculated. Red clover seed was sown on 15th May over the whole area.

Plots 5, 7, and 9 were similarly divided into three plots and sown with cow peas (*Vigna catjang*), a leguminous plant quite new to this land. On E, the seed was inoculated with Moore's medium just before sowing; on F, soil obtained from an old cow pea field in the United States was spread; and G was not inoculated. The cow peas were sown on 16th May, but failed to give a satisfactory plant, and were ploughed up. The plots were sown with red clover in 1906, as part of a further trial of the continuous growth of clover.

HOOS FIELD—WHEAT AFTER FALLOW

The two half-acre plots in Hoos field are never manured, but every year one carries a wheat crop and the other is given a bare summer fallow, the treatment alternating, so that every year one plot is carrying a wheat crop following a bare fallow. By comparing the results obtained with the yield of the unmanured plot growing wheat continuously, the benefit of the bare fallow can be estimated.

TABLE XX.—*Experiments on Wheat, alternated with Fallow, without Manure (Hoos Field)*, 56 *years* (1851-1906); *and grown continuously without Manure (Broadbalk Field)*, 56 *years* (1851-1906).

Average produce of Grain per acre, and Produce last year, 1905.

	Dressed Grain.		
	Wheat after Fallow each year (Hoos Field).	Wheat after Wheat each year (Broadbalk).	After Fallow + or − after Wheat.
AVERAGES—Produce after Fallow, reckoned at the yield per Acre of the half in Crop each year.			
	Bushels.	Bushels.	Bushels.
5 years (1851-55) . . .	19·2	14·7	+ 4·5
10 ,, (1856-65) . . .	26·1	15·9	+10·2
10 ,, (1866-75) . . .	13·5	11·9	+ 1·6
10 ,, (1876-85) . . .	14·8	11·3	+ 3·5
10 ,, (1886-95) . . .	15·1	12·1	+ 3·0
10 ,, (1896-1905) . .	14·3	11·7	+ 2·6
50 ,, (1856-1905) . .	16·7	12·5	+ 4·2
Last year (1905) . . .	12·9	18·0	− 5·1
AVERAGES—Produce after Fallow, reckoned at the yield per Acre of the whole area, half in Crop and half Fallow.			
5 years (1851-55) . . .	9·6	14·7	− 5·1
10 ,, (1856-65) . . .	13·0	15·9	− 2·9
10 ,, (1866-75) . . .	6·8	11·9	− 5·1
10 ,, (1876-85) . . .	7·4	11·3	− 3·9
10 ,, (1886-95) . . .	7·5	12·1	− 4·6
10 ,, (1896-1905) . .	7·2	11·7	− 4·5
50 ,, (1856-1905) . .	8·4	12·5	− 4·1
Last year (1905) . . .	6·4	18·0	−11·6

LITTLE HOOS FIELD

RESIDUAL VALUE OF MANURES

The object of the experiments in this field is to test the residual value of certain typical manures, *i.e.*, the value of the residues left in the soil after one or more crops have been grown since the time of their application. To eliminate the effect of season, the result yielded by the residue is in all cases compared with that of a new application of the same manure, as well as with a continuously unmanured check plot.

The ordinary dung is made by feeding beasts with hay and roots only, the beasts making the cake-fed dung alongside receive also an ordinary allowance of linseed and cotton cake. The two lots of dung are then laid up in heaps for a short time, and weighed out immediately before applying. The yields obtained so far are not given as trustworthy; conclusions can only be drawn when the average over a long period can be taken.

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H.—*Little Hoos Field. Plan of Rotation Plots arranged to test the Residual Value of various Manures—one, two, three, and four years after their application.*

Crops selected—Swedes (1904), Barley (1905), Mangels (1906), and Oats (1907).

Third Year, 1906—Mangels.

Adjoins Hoos Field.

A	5 1907	4 Dung (ordinary) 16 tons per acre, in 1906	3 Dung (ordinary) 16 tons per acre, in 1905	2 Dung (ordinary), 16 tons per acre, in 1904.	1
B	5 1907	4 Dung (Cake-fed), 16 tons per acre, in 1906.	3 Dung (Cake fed) 16 tons per acre, in 1905	2	1 Dung (Cake-fed), 16 tons per acre, in 1904.
C	5 1907	4 Shoddy, 1 ton per acre, in 1906.	3	2 Shoddy, 1 ton per acre, in 1905	1 Shoddy, 1 ton per acre, in 1904.
D	5 1907	4	3 Guano, 8 cwt. per acre, in 1906.	2 Guano, 8cwt. per acre, in 1905.	1 Guano, 8 cwt per acre, in 1904.
E	5	4 1907	3 Rape-cake, 10 cwt. per acre, in 1906.	2 Rape-cake, 10cwt. per acre, in 1905	1 Rape-cake, 10 cwt per acre, in 1904
F	5 1907	4 Superphosphate, 600 lb per acre, in 1906.	3 Superphosphate, 600 lb. per acre. in 1905.	2 Superphosphate, 600 lb. per acre, in 1904.	1
G	5 1907	4 Bone Meal, 430 lb. per acre, in 1906.	3	2 Bone Meal, 430 lb. per acre in 1905	1 Bone Meal, 430 lb. per acre, in 1904.
H	5	4 1907	3 Basic Slag, 600 lb. per acre, in 1906.	2 Basic Slag 600 lb. per acre. in 1905.	1 Basic Slag, 600 lb per acre, in 1904

Each plot received 3 cwt. Superphosphate per acre in 1904, and 3 cwt. of Sulphate of Potash in 1906. (Series A–E)

Each plot received 1 cwt. of Sulphate-Ammonia per acre in 1904 and 1905, and 2 cwt. in 1906, with 3 cwt. of Sulphate of Potash. (Series F–H)

Adjoins Broadbalk Field. Area of each plot $\frac{1}{8}$th acre.

Series A deals with the residual effects of Ordinary Dung.
,, B ,, ,, ,, Cake-fed Dung.
,, C ,, ,, ,, Shoddy.
,, D ,, ,, ,, Guano.
,, E ,, ,, ,, Rape-cake.
,, F ,, ,, ,, Superphosphate.
,, G ,, ,, ,, Bone-Meal.
,, H ,, ,, ,, Basic Slag.

In each series the manure is applied to one plot in 1904, to another plot in 1905, to a third plot in 1906, and to a fourth plot in 1907.

All the plots in the Series A to E, which deal with Nitrogenous Manures, receive, as necessary, equal amounts of Phosphates and Potash. Similarly, all the plots in the Series F, G, H, dealing with Phosphatic Manures, receive equal dressings of Nitrogenous or Potassic Manures as required.

Check plots receiving in Series A to E no Nitrogen throughout, Series F to H no Phosphates throughout.