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AGRICULTURAL INVESTIGATION;

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AT

RUTGERS COLLEGE, NEW BRUNSWICK, N. J.

UNDER THE AUSPICES OF

THE NEW JERSEY AGRICULTURAL EXPERIMENT STATION,  
THE STATE BOARD OF AGRICULTURE, AND  
THE STATE AGRICULTURAL COLLEGE;

BY

JOHN HENRY GILBERT, M. A., LL. D., F. R. S.

OF ROTHAMSTED, ENGLAND.

AND SIBTHORPIAN PROFESSOR OF RURAL ECONOMY  
IN THE UNIVERSITY OF OXFORD.



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NOTE ON DR. GILBERT'S LECTURE.

It has been announced that Sir John Bennet Lawes, in arranging for the perpetual maintenance of the great work of Rothamsted, makes provision for a representative of that establishment to visit America every other year and lecture at appropriate places.

Dr. Gilbert was in the United States in 1882, and when it was known that he was to come again in 1884, efforts were made to have him attend the fifth annual meeting of the Society for the Promotion of Agricultural Science. As his various engagements unfortunately prevented his being in Philadelphia at the time desired, arrangements were there made to secure lectures from him at other places. He accordingly visited Lansing, Michigan, and New Brunswick, New Jersey, for the purpose, and found appreciative audiences at both places.

The lecture at Rutgers College was under the joint auspices of the New Jersey Agricultural Experiment Station, State Agricultural College, and State Board of Agriculture.

The Society for the Promotion of Agricultural Science, having intended this lecture to be a part of its proceedings at Philadelphia, have asked and obtained permission to first publish the same in this pamphlet. For this purpose the text has been carefully revised and the tables verified by Dr. Gilbert. This kind attention is gratefully acknowledged by

THE EXECUTIVE COMMITTEE.

## LECTURE ON AGRICULTURAL INVESTIGATIONS.

J. H. GILBERT.

*Mr. President, Professors and Students of Rutgers College,  
and Ladies and Gentlemen :*

I ESTEEM it a high honor and a great responsibility to be called upon to address you on the present occasion ;—an honor because, perhaps, I am not assuming too much in supposing that I owe the invitation to do so to the fact that the joint labors of Sir John Bennet Lawes and myself, in the furtherance of agricultural progress, which have now extended over a period of more than forty-one years, are held in some appreciation in this country ;—and a responsibility, because I know that I have before me representatives of the best agricultural science in the Eastern States.

On hearing from Sir John Lawes, before leaving home, that I might probably be asked to lecture at some Agricultural Institutions in America, I at once decided that it would be inappropriate for me to attempt to discuss, in any detail, American agricultural practices or experiments ; that in these matters I should be a learner rather than a teacher ; and that it would be more suitable for me to give some account of the results obtained at Rothamsted, leaving my audience to decide for themselves, in great measure, how far the facts and the conclusions were applicable to American conditions.

In Germany and France very much good work has been done, both in the laboratory and feeding-shed, during the last thirty years or more ; but in Germany, at any rate, we have it on the authority of Prof. Mærcker of Halle, one of their leading agricultural chemists, that systematic field experiments are almost abandoned in that country. In 1880, Prof. Mærcker stated that belief in their value was greatly diminished, and that by some they were declared to be of no value. It was objected that the chemists of the Agricultural Stations have neither the means nor the technical knowledge necessary for carrying out such experiments successfully ; that neither the amount of land nor the funds at their disposal were such as to admit of any safe deductions for application in practical agriculture from the results ; and that purely physiological problems could be better investigated in the laboratory or in the greenhouse. He remarked that, owing to the errors necessarily incident to field experiments conducted by those not acquainted with practical agriculture, the confidence of the practical farmer in the results has been shaken. Indeed, owing to the difficulties and the cost of such inquiries,

if conducted in a truly scientific manner, so as to be applicable for the solution of questions of fundamental and general interest, Prof. Mærcker concluded that the only field experiments which it was practicable to carry out in Germany were such as should be conducted by the practical farmer himself, to test the applicability to practice, of results and conclusions otherwise arrived at; and that, to insure that even such experiments should not be misleading, similar ones should be conducted on different descriptions of soil, and for several years in succession.

That the great cost of scientifically conducted field experiments should have prevented the more extended prosecution of them, is perhaps not surprising when I tell you that the Rothamsted field experiments, independently of all the laboratory investigations connected with them, cost considerably more than £1000 annually; whilst those which have been undertaken by the Duke of Bedford at Woburn for the past seven years, on behalf of the Royal Agricultural Society of England, and which are under the direction of Dr. Vœlcker, cost not much less than this.

At various institutions in America, and preëminently at the New Jersey Agricultural Experiment Station, very much good work is being done of the character prosecuted with so much success in Germany, and recommended by Prof. Mærcker to be still further followed up; and whilst such work should be continued and extended, surely investigations of a more permanent value, and of more general application, should not be neglected. Nor can it be supposed that in so wealthy a country as America, where there is so much munificence and public spirit displayed in all matters of progress, the *cost* of scientifically conducted agricultural experiments will be any obstacle.

This brings me to the special subject-matter of my lecture, which is to illustrate the value of *long continued* and *carefully conducted* experiments, by reference to the results of one series of such experiments conducted at Rothamsted,—namely, those on the growth of wheat for more than forty years in succession on the same land—*without manure, with farm-yard manure, and with a great variety of chemical manures.*

But, before entering upon the details of this subject, it will be well to give some account of the scope and plan of the whole investigation, of which these special results only form a part.

At Rothamsted, no questions of mere local interest or economy are undertaken. The object is rather to investigate the principles underlying fundamental practices; and whilst results obtained in one locality, on one description of soil, and with one character of climate, require to be carefully studied before conclusions applicable to other localities and to other countries can be drawn, yet it is believed that the results which have been obtained are of very general and wide application.

The general scope and plan of the field experiments has been—to grow some of the most important crops of rotation, each separately, year after year, for many years in succession on the same land, without manure, with farm-yard manure, and with a great variety of chemical manures, the same description of manure being, as a rule, applied year after year on the same plot. Experiments with different manures on the mixed herbage of permanent grass-land, on the effects of fallow, and on an actual course of rotation, without manure, and with different manures, have likewise been made. Field experiments have thus been conducted for the periods, and over the areas, indicated in the following table:

## ROTHAMSTED FIELD EXPERIMENTS.

CROPS.	DURATION YEARS.	AREA, ACRES.	PLOTS.
Wheat (various manures).....	41	13	37
Wheat alternated with fallow .....	33	1	2
Wheat (varieties) .....	15	4-8	About 20
Barley (various manures).....	33	4 $\frac{1}{4}$	29
Oats (various manures).....	10 <sup>1</sup>	3 $\frac{3}{4}$	6
Beans (various manures).....	32 <sup>2</sup>	1 $\frac{1}{4}$	10
Beans (various manures).....	27 <sup>3</sup>	1	5
Beans alternated with wheat .....	28 <sup>4</sup>	1	10
Clover (various manures) .....	30 <sup>5</sup>	3	18
Various Leguminous Plants .....	7	3	17
Turnips (various manures).....	28 <sup>6</sup>	8	40
Sugar Beet (various manures).....	5	8	41
Mangel Wurzel (various manures).....	9	8	41
Total Root Crops.....	42		
Potatoes (various manures).....	9	2	10
Rotation (various manures).....	37	2 $\frac{1}{2}$	12
Permanent Grass (various manures)....	29	7	22

(<sup>1</sup>) Including 1 year fallow.

(<sup>2</sup>) " 1 " wheat and 5 years fallow.

(<sup>3</sup>) " 4 years fallow.

(<sup>4</sup>) " 2 " "

(<sup>5</sup>) Clover, 12 times sown, 8 yielding crops, but 4 of them very small, 1 year wheat, 5 years barley, 12 years fallow.

(<sup>6</sup>) Including barley without manure 3 years (11th, 12th and 13th seasons.)

Samples of all the experimental crops are brought to the laboratory. Weighed portions of each are partially dried and preserved for future reference or analysis. Duplicate weighed portions of each are dried at 100° C., the dry matter determined, and then burnt to ash. The quantities of ash are determined and recorded, the ashes themselves being preserved for reference or analysis. In a large proportion of the samples the total nitrogen is determined, and in some the amount existing as albuminoids, amides, and nitric acid. In selected cases, illustrating the influence of season, manures, exhaustion, etc., complete ash-analyses have been made, numbering in all more than 700. Also in selected cases, illustrating the influence of season and manuring, quantities of the experimentally grown wheat-grain have been sent to the mill, and the proportion and composition of the different mill-products has been determined. In the sugar-beet, mangel-wurzel, turnips, and potatoes, the sugar in the juice has, in many cases, been determined, by polariscope, or by copper, or both. In the case of the experiments on the mixed herbage of permanent grass-land, besides the samples taken for the determination of the chemical composition (dry matter, ash, nitrogen, woody fiber, fatty matter, and composition of ash), carefully averaged samples have frequently been taken for the determination of the botanical composition.

Samples of the soils of most of the experimental plots have been taken from time to time, generally to the depth of nine, eighteen, and twenty-seven inches, and sometimes even to four times this depth. In this way more than fifteen hundred samples have been taken, submitted

to partial mechanical separation, and portions of the sifted soil have been carefully prepared and preserved for analysis. In a large proportion of the samples the loss on drying at different temperatures, and at ignition, has been determined. In most, the nitrogen determinable by burning with soda-lime has been estimated. In many, the carbon, and in some the nitrogen, as nitric acid, and the chlorine, have been determined.

Almost from the commencement of the experiments the rain-fall has been measured; for more than thirty years in a gauge of one-thousandth of an acre area, as well as in an ordinary small funnel-gauge of five inches diameter. From time to time the nitrogen as ammonia (and sometimes as nitric acid) has been determined in the rain-waters, also chlorine in many samples.

Three drain-gauges, for the determination of the quantity and composition of the water percolating, respectively through twenty inches, forty inches, and sixty inches depth of soil (with its subsoil in natural state of consolidation), have also been constructed. Each of the differently manured plots of the permanent experimental wheat-field having a separate pipe-drain, the drainage waters have been, and are frequently, connected and analyzed.

For several years in succession experiments were made to determine the amount of water given off by plants during their growth. In this way various plants, including representatives of the gramineous, the leguminous, and other families, have been experimented upon; also ever-green and deciduous trees.

Experiments upon the feeding of animals were commenced in 1847, and have been continued at intervals up to the present time. The following points have been investigated:

1. The amount of food, and its several constituents, consumed in relation to a given live-weight of animal within a given time.
2. The amount of food, and of its several constituents, consumed to produce a given amount of increase in live-weight.
3. The proportion, and relative development, of the different organs or parts of different animals.
4. The proximate and ultimate composition of the animals, in different conditions as to age and fatness, and the probable composition of their increase in live-weight during the fattening process.
5. The composition of the solid and liquid excreta (the manure) in relation to that of the food consumed.
6. The loss or expenditure of constituents by respiration and the cutaneous exhalations — that is, in the mere sustenance of the living meat-and-manure-making machine.

Several hundred animals — oxen, sheep, and pigs — have been submitted to experiment. The amount, and the relative development, of the different organs and parts were determined in two calves, two heifers, fourteen bullocks, one lamb, two hundred and forty-nine sheep, and fifty-nine pigs. The percentages of water, mineral matter, fat, and nitrogenous substances were determined in certain separated parts, and in



TABLE I.

Wheat grown for forty years in succession on the same land, Broadbalk Field, Rothamsted. Results showing the effects of exhaustion, and of manure-residue. Quantities per acre. Produce—Dressed Grain in bushels.

Plot Nos.	14 Tons Farm Yard Manure, every year.	Without Manure every year.	Mixed Mineral Manure alone.	Mixed Mineral Manure alone, — blue; Ammonium Salts alone=86 lbs. Nitrogen, — yellow; alternately.		Mixed Min. Manr Am. Salts. 172 lbs. N. 13 years, 1852-'64. Unman'd since.	Mineral Manure alone—blue; Ammonium Salts alone (86 lbs. Nitrogen)—yellow; Min. & Amm. Salts, —green; Unmanured—white.	
	2	3	5	17	18	16	10a	10b
Harvests.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.
1844	20½	15					15½	
1845	32	23½					31½	
1846	27½	18					27%	17½
1847	29%	16%					25%	25%
1848	25%	14%					19½	25%
1849	31	19½					32%	32%
1850	28½	15%					27	18
1851	29%	15%					28%	28%
8 yrs. '44-'51	28	17%	29	30¼	28%	30¾	26	24%
1852	27%	13%	16%	24%	14%	28½	21%	22%
1853	19%	5%	10%	8%	19½	25%	10	15½
1854	41%	21%	24%	44½	23%	49%	34%	39½
1855	34%	17	18½	18	33½	32%	20	28%
1856	36½	14½	19½	31	17%	37%	24½	27%
1857	41¼	20	23%	26½	40½	49%	29½	34½
1858	38¾	18	18%	33½	21½	41%	22%	27%
1859	36¼	18%	20%	20½	32%	34%	19	25½
1860	32¼	12%	15%	25½	15½	32%	15½	18%
1861	34%	11%	15½	18%	32%	37	12%	16
1862	38%	16	17%	27%	18½	36½	23%	24%
1863	44	17½	19%	21½	46½	55%	39%	43%
1864	40	16%	16%	36%	17%	51%	32%	36½
1865	37	13%	14½	17	31%	32%	25½	30½
1866	32%	12%	13½	26½	12%	17%	26½	28½
1867	27½	8%	9½	10%	23%	14%	18½	19%
1868	41%	16%	17%	37%	18%	22%	24%	27%
1869	38½	14%	15%	16%	22%	16%	20½	19%
1870	36½	15	18%	34%	19	18½	21%	23½
1871	39	9%	11%	16	28%	13%	10%	10
1872	31%	10%	12%	25%	13	13%	18	18%
1873	26%	11%	12%	11%	20%	12%	19%	20%
1874	39½	11%	13	33½	14	11%	25½	27%
1875	28%	8%	9½	11%	25%	10%	12%	14%
1876	23%	8%	10%	26½	10%	11	12%	14½
1877	24%	8%	11%	10	12%	9%	17½	18½
1878	28%	12%	14%	29	15½	13%	27%	29%
1879	16	4%	5%	3%	20%	4%	4	4%
1880	38%	11%	17%	32%	15	14%	10%	13%
1881	30¼	13%	12%	13%	32	13%	18½	19%
1882	32%	11	12%	31	15%	10%	23%	26½
1883	35¼	13%	15%	15%	38½	15%	17½	18%

AVERAGES.

4 yrs. '52-'55	30%	14½	17%	16¼	30%	34	21½	26¼
4 yrs. '56-'59	38	17%	20%	21%	34%	41	23%	28%
4 yrs. '60-'63	37%	14%	17½	18½	33	(1) 42%	22½	25%
4 yrs. '64-'67	34½	12%	13%	14½	29%	(2) 21½	25½	28%
4 yrs. '68-'71	38%	13%	16	17%	30%	17%	19½	20
4 yrs. '72-'75	31%	10%	12	12%	26%	12	18%	20½
4 yrs. '76-'79	23	8½	10%	9%	22%	9%	15½	16%
4 yrs. '80-'83	34%	12½	14%	14%	33%	13%	17½	19%
8 yrs. '52-'59	34%	16½	19	18%	32%	37½	22%	27%
8 yrs. '60-'67	35%	13½	15½	16%	31%	(3) 42%	24	27½
8 yrs. '68-'75	35%	12½	14	15	28½	(4) 16%	19	20%
8 yrs. '76-'83	28%	10½	12%	12%	27%	11%	16%	18%
16 yrs. '52-'67	35%	14%	17%	17%	31%	(5) 39½	23%	27%
16 yrs. '68-'83	31%	11%	13%	13%	28%	(6) 14%	17%	19%
32 yrs. '52-'83	33½	13%	15½	15%	30		20½	23½
40 yrs. '44-'83	32%	14						

(1) Average of 5 years, 1860—1864, inclusive. (2) Average of 3 years, 1865—1867, inclusive.  
 (3) Average of 5 years, 1860—1864, inclusive. (4) Average of 11 years, 1865—1875, inclusive.  
 (5) Average of 13 years, 1852—1864, inclusive. (6) Average of 19 years, 1865—1883, inclusive.

the entire bodies, of ten animals,—namely, one calf, two oxen, one lamb, four sheep, and two pigs. Complete analyses of the ashes, respectively, of the entire carcasses, of the mixed internal and other “offal” parts, and of the entire bodies, of each of these ten animals, have also been made.

From the data provided as just described, as to the chemical composition of the different descriptions of animal, in different conditions as to age and fatness, the composition of the increase whilst fattening, and the relation of the constituents stored up in increase to those consumed in food, have been estimated. To ascertain the composition of the manure in relation to that of the food consumed, oxen, sheep, and pigs have been experimented upon. The loss or expenditure of constituents, by respiration and the cutaneous exhalations, has not been determined directly, but only by difference,—that is, by calculation, founded on the amounts of dry matter, ash, nitrogen, etc., in the food, and in the (increase) fœces, and urine.

Independently of the points here enumerated, the results obtained have supplied data for the consideration of the following questions :

1. The characteristic demands of the animal body, for nitrogenous or non-nitrogenous constituents of food, in the exercise of muscular power.
2. The sources in the food of the fat produced in the animal body.
3. The comparative characters of animal and vegetable food in human dietaries.

Having given a brief outline of the scope and plan of the investigations that have been in progress at Rothamsted for so many years, I propose to draw my illustrations as to the character and significance of the results obtained, mainly from those relating to the growth of wheat for more than forty years in succession on the same land :

1. Without manure.
2. With farm-yard manure.
3. With a great variety of chemical manures, both individual constituents and mixtures.

Table I. gives the number of bushels of dressed grain per acre without manure, and with farm-yard manure, in each of the forty years, 1844 to 1883 inclusive; and on some of the artificially manured plots, mainly selected to illustrate the effects of exhaustion and of manure-residue. In most cases in this table, and in all cases in the subsequent tables, the results obtained on the artificially manured plots are only given for the last thirty-two of the forty years, as during the first eight years the manures were not the same year after year on the same plot as they were subsequently.

#### FIRST. WITHOUT MANURE.

After a five-course rotation since manuring (turnips, barley, peas, wheat, oats), the first experimental wheat crop was harvested in 1844. The highest yield of the series was  $23\frac{1}{4}$  bushels in 1845, and the lowest

was  $4\frac{3}{4}$  bushels in 1879. Other yields have been  $21\frac{1}{8}$  bushels in 1854, 20 in 1857, only  $5\frac{7}{8}$  in 1853, and only 8-9 bushels in 1867, 1875, 1876, and 1877.

In the lower division of the table (I.) the average produce is given for each four years, each eight years, each sixteen years, and for the thirty-two years from 1852 to 1883 inclusive; also for the whole period of forty years. Without manure, the average annual produce over the four-year periods was  $14\frac{1}{2}$ ,  $17\frac{3}{4}$ ,  $14\frac{3}{8}$ ,  $12\frac{3}{4}$ ,  $13\frac{3}{4}$ ,  $10\frac{5}{8}$ ,  $8\frac{1}{2}$ , and  $12\frac{1}{2}$  bushels; over the eight-year periods,  $16\frac{1}{8}$ ,  $13\frac{1}{2}$ ,  $12\frac{1}{4}$ , and  $10\frac{1}{2}$ ; over the sixteen-year periods,  $14\frac{7}{8}$  and  $11\frac{3}{8}$ ; over the thirty-two years,  $13\frac{1}{8}$ , and over the forty years, 14 bushels. With such wide variations due to season, it is very difficult to estimate the rate of decline due to exhaustion. Excluding the very bad seasons, the decline due to gradual exhaustion is reckoned at from one-fourth to one-third of a bushel per acre per annum.

It is estimated that over a period of thirty years the unmanured plot yielded an average of 18.6 lbs. of nitrogen per acre per annum in the crop, and lost a minimum of 10.3 lbs. in drainage, in all 28.9 lbs.; whilst on the mixed mineral manure plot (5), it is estimated that the crop removed an average of 20.3 lbs. of nitrogen, and that at least 12 lbs. were lost by drainage, or in total 32.3 lbs. Further it is estimated that the soils lost to the depth of twenty-seven inches about two-thirds of these amounts; leaving, say, 10 lbs. more or less to be otherwise accounted for. Of this, the rain, etc., would supply 5 lbs., or perhaps rather more, and the seed about 2 lbs., so that there is but little to be provided from all other sources. Lastly, as at the commencement the soil was, agriculturally speaking, exhausted, the nitrogen supplied by it would be largely due to old accumulations.

## SECOND. FARM-YARD MANURE EVERY YEAR.

In the application of farm-yard manure every constituent is supplied in excess. The highest yields of the series of years were 44 bushels in 1863,  $41\frac{3}{4}$  in 1868,  $41\frac{1}{4}$  in 1857, and  $41\frac{1}{8}$  in 1854. The lowest yields were 16 bushels in 1879,  $19\frac{1}{8}$  in 1853,  $20\frac{1}{2}$  in 1844,  $23\frac{7}{8}$  in 1876, and  $24\frac{1}{8}$  in 1877.

The average produce per acre per annum over each of the five eight-year periods was, 28,  $34\frac{3}{8}$ ,  $35\frac{3}{4}$ ,  $35\frac{1}{4}$ , and  $28\frac{5}{8}$  bushels. Excluding the first eight years, and several of the recent very bad seasons, the average produce is about 35 bushels per acre per annum.

On the farm-yard manure plot, the first nine inches of soil show a great accumulation; it is nearly twice as rich in nitrogen as any other plot, yet this richness is not proof against bad seasons; nor are the highest amounts of produce in the field obtained on this plot.

Thus, without manure, or with mineral manure alone, there is a gradual decline in yield, and with this a marked reduction in the nitrogen of the soil. With farm-yard manure, on the other hand, there is great accumulation, and yet not the fullest crops, a large proportion of the constituents becoming very slowly available.

The next question is, which constituents of farm-yard manure are the most effective for wheat in this agriculturally exhausted rather heavy soil, with a raw clay subsoil. The first illustrations on this point will be drawn from Table II.

TABLE II.

Wheat grown for forty years in succession on the same land,  
Broadbalk Field, Rothamsted; commencing 1844.

Results showing the effects of different manures for 32 years, 1852-83 inclusive. Quantities per acre. Produce—DRESSED GRAIN IN BUSHEL.

Plots.	Superphosphate, and Sulphates Potash, Soda, and Magnesia.					Sodium Nitrate alone. =86 lbs. Nitrogen.
	Alone.	& Amm.-salts =43 lbs. Nitrogen.	& Amm.-salts =86 lbs. Nitrogen.	& Amm.-salts =129 lbs. Nitrogen.	& Sodium Nitrate =86 lbs. Nitrogen.	
	5	6	7	8	9a	9b
Harvests.	5	6	7	8	9a	9b
1852	16 $\frac{7}{8}$	20 $\frac{7}{8}$	26 $\frac{3}{4}$	27 $\frac{3}{4}$	25 $\frac{3}{4}$	24 $\frac{3}{4}$
1853	10 $\frac{3}{4}$	18 $\frac{3}{4}$	23 $\frac{3}{4}$	23 $\frac{3}{4}$	11 $\frac{3}{4}$	10 $\frac{3}{4}$
1854	24 $\frac{1}{4}$	34 $\frac{1}{4}$	45 $\frac{1}{2}$	48 $\frac{1}{2}$	38 $\frac{1}{2}$	38 $\frac{1}{2}$
1855	18 $\frac{1}{4}$	28	33	31 $\frac{1}{2}$	29 $\frac{3}{8}$	25 $\frac{3}{8}$
1856	19 $\frac{1}{2}$	27 $\frac{3}{4}$	36 $\frac{1}{2}$	39 $\frac{1}{2}$	32 $\frac{3}{4}$	26
1857	23 $\frac{1}{2}$	35 $\frac{1}{2}$	44 $\frac{1}{2}$	48 $\frac{1}{2}$	43 $\frac{1}{2}$	36 $\frac{1}{2}$
1858	18 $\frac{7}{8}$	28 $\frac{7}{8}$	39 $\frac{1}{8}$	41	37 $\frac{3}{8}$	23 $\frac{1}{2}$
1859	20 $\frac{3}{8}$	29 $\frac{3}{8}$	34 $\frac{3}{8}$	34 $\frac{3}{8}$	30	24 $\frac{3}{8}$
1860	15 $\frac{1}{4}$	22	27 $\frac{3}{4}$	31 $\frac{1}{4}$	32 $\frac{3}{4}$	19 $\frac{1}{4}$
1861	15 $\frac{1}{2}$	27 $\frac{5}{8}$	35	35 $\frac{5}{8}$	33 $\frac{5}{8}$	13 $\frac{5}{8}$
1862	17 $\frac{3}{4}$	28	35 $\frac{3}{4}$	39 $\frac{3}{4}$	43 $\frac{3}{4}$	25 $\frac{3}{4}$
1863	19 $\frac{3}{8}$	39 $\frac{3}{8}$	53 $\frac{3}{8}$	55 $\frac{3}{8}$	55 $\frac{3}{8}$	41 $\frac{3}{8}$
1864	16 $\frac{7}{8}$	31 $\frac{1}{8}$	45 $\frac{3}{8}$	49 $\frac{7}{8}$	51 $\frac{1}{8}$	33 $\frac{1}{4}$
1865	14 $\frac{1}{4}$	25	40 $\frac{1}{4}$	43 $\frac{3}{4}$	44 $\frac{3}{8}$	29 $\frac{3}{8}$
1866	13 $\frac{1}{4}$	20 $\frac{1}{2}$	29 $\frac{1}{2}$	32 $\frac{1}{2}$	32 $\frac{1}{2}$	30 $\frac{1}{2}$
1867	9 $\frac{1}{4}$	15 $\frac{3}{4}$	22 $\frac{1}{8}$	30 $\frac{1}{2}$	29 $\frac{1}{8}$	22 $\frac{1}{8}$
1868	17 $\frac{5}{8}$	28 $\frac{1}{2}$	39 $\frac{7}{8}$	46 $\frac{3}{4}$	47 $\frac{5}{8}$	27 $\frac{1}{4}$
1869	15 $\frac{1}{2}$	21	28	34 $\frac{1}{2}$	39	24 $\frac{1}{2}$
1870	18 $\frac{7}{8}$	30 $\frac{2}{8}$	40 $\frac{2}{8}$	45 $\frac{5}{8}$	45 $\frac{5}{8}$	26 $\frac{5}{8}$
1871	11	17	22 $\frac{1}{4}$	27 $\frac{3}{4}$	34 $\frac{3}{4}$	17
1872	12 $\frac{3}{4}$	20 $\frac{3}{4}$	29 $\frac{3}{4}$	35 $\frac{3}{4}$	40 $\frac{3}{4}$	23 $\frac{3}{8}$
1873	12 $\frac{3}{4}$	15 $\frac{7}{8}$	22	27 $\frac{3}{8}$	35 $\frac{5}{8}$	21 $\frac{3}{8}$
1874	13	25 $\frac{3}{4}$	39 $\frac{1}{2}$	40 $\frac{3}{2}$	38 $\frac{1}{2}$	21 $\frac{1}{2}$
1875	9 $\frac{1}{2}$	16 $\frac{3}{8}$	25 $\frac{3}{8}$	30	30 $\frac{1}{2}$	16 $\frac{1}{2}$
1876	10 $\frac{1}{2}$	15 $\frac{3}{4}$	23 $\frac{3}{4}$	29 $\frac{3}{4}$	33 $\frac{3}{4}$	13
1877	11 $\frac{3}{8}$	14 $\frac{3}{8}$	19 $\frac{3}{8}$	24 $\frac{3}{8}$	40 $\frac{3}{8}$	27 $\frac{3}{8}$
1878	14 $\frac{3}{8}$	22 $\frac{3}{8}$	31 $\frac{3}{8}$	38 $\frac{3}{8}$	37 $\frac{1}{4}$	23 $\frac{3}{8}$
1879	5 $\frac{5}{8}$	10 $\frac{3}{8}$	16 $\frac{1}{4}$	20 $\frac{3}{8}$	22	4 $\frac{5}{8}$
1880	17 $\frac{3}{4}$	27	34 $\frac{3}{4}$	35 $\frac{3}{4}$	34 $\frac{3}{4}$	10 $\frac{3}{4}$
1881	12 $\frac{3}{4}$	21 $\frac{3}{4}$	26 $\frac{3}{4}$	30 $\frac{3}{4}$	35 $\frac{3}{4}$	22 $\frac{3}{4}$
1882	12 $\frac{1}{4}$	23	35 $\frac{1}{4}$	37	31 $\frac{7}{8}$	24 $\frac{3}{8}$
1883	15 $\frac{1}{4}$	27 $\frac{3}{4}$	36 $\frac{3}{4}$	41 $\frac{3}{4}$	43 $\frac{3}{4}$	19 $\frac{3}{4}$

## AVERAGES.

4 ys. '52-55	17 $\frac{3}{8}$	25 $\frac{1}{4}$	32 $\frac{1}{4}$	32 $\frac{3}{4}$	26 $\frac{1}{4}$	24 $\frac{3}{8}$
4 ys. '56-59	20 $\frac{3}{8}$	30	38 $\frac{5}{8}$	41	36	27 $\frac{1}{8}$
4 ys. '60-63	17 $\frac{1}{4}$	29 $\frac{3}{8}$	38	40 $\frac{3}{8}$	41 $\frac{3}{8}$	25 $\frac{1}{4}$
4 ys. '64-67	13 $\frac{3}{8}$	23 $\frac{3}{4}$	34 $\frac{1}{2}$	39	39 $\frac{1}{2}$	29
4 ys. '68-71	16	24 $\frac{3}{8}$	32 $\frac{3}{4}$	38 $\frac{3}{4}$	41 $\frac{3}{4}$	23 $\frac{7}{8}$
4 ys. '72-75	12	19 $\frac{3}{8}$	29 $\frac{1}{4}$	33 $\frac{3}{8}$	36 $\frac{3}{8}$	20 $\frac{7}{8}$
4 ys. '76-79	10 $\frac{5}{8}$	15 $\frac{3}{4}$	22 $\frac{3}{4}$	28 $\frac{3}{4}$	33 $\frac{1}{4}$	17 $\frac{1}{4}$
4 ys. '80-83	14 $\frac{3}{4}$	24 $\frac{3}{4}$	33 $\frac{1}{4}$	36 $\frac{1}{4}$	36 $\frac{1}{4}$	19 $\frac{1}{4}$
8 ys. '52-59	19	27 $\frac{5}{8}$	35 $\frac{3}{4}$	36 $\frac{5}{8}$	31 $\frac{5}{8}$	26 $\frac{1}{4}$
8 ys. '60-67	15 $\frac{1}{4}$	26 $\frac{1}{4}$	36 $\frac{1}{4}$	39 $\frac{1}{4}$	40 $\frac{1}{4}$	27 $\frac{3}{8}$
8 ys. '68-75	14	22	31	36	39	22 $\frac{3}{8}$
8 ys. '76-83	12 $\frac{5}{8}$	20 $\frac{3}{8}$	28	32 $\frac{1}{4}$	34 $\frac{3}{4}$	18 $\frac{1}{4}$
16 ys. '52-67	17 $\frac{1}{4}$	27	35 $\frac{1}{4}$	38 $\frac{1}{4}$	35 $\frac{3}{4}$	26 $\frac{3}{8}$
16 ys. '68-83	13 $\frac{3}{8}$	21 $\frac{1}{4}$	29 $\frac{1}{2}$	34 $\frac{1}{8}$	36 $\frac{7}{8}$	20 $\frac{1}{4}$
32 ys. '52-83	15 $\frac{1}{4}$	24 $\frac{3}{8}$	32 $\frac{3}{4}$	36 $\frac{1}{4}$	36 $\frac{1}{4}$	23 $\frac{3}{4}$
Excess of average crop over Plot 5 in bush.)	—	8 $\frac{7}{8}$	17 $\frac{1}{2}$	21	21	8 $\frac{1}{4}$

Taking the average for each eight or sixteen years of the thirty-two, it is seen that in every case, even with full mineral as well as nitrogenous manure, there is more or less decline in the later periods including so many bad seasons; excepting on 9a, where the nitrate of soda is always applied in the spring. The low results or great decline, on 9b, where the nitrate is used alone, show the want of minerals.

The average of the thirty-two years of mineral manure alone shows an increase of only  $2\frac{1}{8}$  bushels over that of the unmanured plot, though during the preceding eight years it had been manured, whilst the unmanured plot had already grown eight unmanured wheat crops. The addition to the mineral manure of the first 43 lbs. of nitrogen (plot 6) gives an average annual increase of  $8\frac{7}{8}$  bushels, the second 43 lbs. (plot 7) an increase of  $8\frac{5}{8}$ , and the third 43 lbs. only  $3\frac{1}{2}$  bushels increase. This result affords an illustration of the inapplicability of conclusions from manure experiments, when the condition of the land is too high already, or when an excess of manure is applied. A given quantity of nitrogen in the form of nitrate, yielded more produce than an equal quantity in the form of ammonia. The nitrate, being always applied in the spring, was not subject to winter drainage. It is, however, very soluble, and becomes rapidly distributed and available; but it is, at the same time, very subject to drainage after sowing, if heavy rains follow. Prior to 1878, the ammonium-salts were applied in the autumn, and a great loss of nitrogen by winter drainage, chiefly as nitrates, was proved. To the loss of nitrogen by drainage reference will be made further on.

Thus, minerals not being deficient, the increase was in proportion to the available nitrogen, when it was not applied in excess.

It will be of interest here to call attention to the actual amounts of carbon assimilated per acre per annum in wheat, and in barley, under different conditions of manuring; also to the increased amount assimilated under the influence of nitrogenous manures.

In Table III. are shown the estimated amounts of carbon, yielded per acre per annum, in wheat over twenty years, and in barley over twenty years; each with the complex mineral manure alone, and each with the same mineral manure and given quantities of nitrogen in addition, supplied as ammonium-salts, or as nitrate. The gain of carbon by the use of the nitrogenous manure is also given.

TABLE III.

Yield and gain of Carbon per acre per annum in crops at Rothamsted.

	Average Carbon per acre per annum.	
	ACTUAL LBS.	LBS. GAIN.
Wheat 20 years—1852, '71.		
Complex Mineral Manure. . . . .	988	—
do do and 43 lbs. N. as Ammonia	1590	602
do do and 86 lbs. N. as Ammonia	2222	1234
do do and 86 lbs. N. as Nitrate. . .	2500	1512
Barley 20 years—1852, '71.		
Complex Mineral Manure, . . . . .	1138	—
do do and 43 lbs. N. as Ammonia	2088	950

It is quite evident that in the case of these gramineous crops, wheat and barley, which contain a comparatively low percentage of nitrogen, and assimilate a comparatively small amount of it over a given area, there was a greatly increased amount of carbon assimilated by the addition of nitrogenous manure alone. In the case of the wheat, there was much more effect from a given amount of nitrogen supplied as nitrate, which was always applied in the spring, than from an equal quantity as ammonium-salts, which were applied in the autumn and the nitrogen of which was subject to winter drainage. There is also more effect from ammonium-salts applied to barley than to wheat; the application having been made for the former in the spring and for the latter in the autumn. It should be observed that there was this greatly increased assimilation of carbon in the wheat and in the barley for more than twenty years, without the addition of any carbon to the soil. It is, indeed, certain that, in the existing condition of our old arable soils, the increased growth of our staple starch-yielding grains is greatly dependent on a supply of nitrogen within the soil. It is equally certain that the increased production of sugar in the gramineous sugar-cane, in the tropics, is likewise greatly dependent on the supply of nitrogen within the soil.

It will further be of interest to call attention to the connection between nitrogen accumulation, chlorophyl formation, and carbon assimilation.

TABLE IV.

Relation of Carbon assimilation to Nitrogen accumulation, and to Chlorophyl formed.

	Nitrogen percentage in Dry Matter.*	Relative Amount of Chlorophyl.	Carbon per acre per annum=lbs.	
			Actual	Difference.
HAY.				
Gramineæ, .....	1.900	0.77	—	—
Leguminosæ, .....	2.478	2.40	—	—
WHEAT.				
Plot 10a, .....	(1.227)	2.00	1398	-824
Plot 7, .....	(0.566)	1.00	2222	—
BARLEY.				
Plot 1a, .....	(1.474)	3.20	1403	-685
Plot 4a, .....	(0.792)	1.46	2088	—

\* The figures given in parenthesis are on the substance partially dried, but not fully dried at 100° C.

It should be observed that the amounts of chlorophyl recorded are as stated, *relative*, and not actual; and the figures show the relative amounts for the individual members of each pair of experiments, and not the comparative amounts as between one set of experiments and another. It should further be stated that the chlorophyl determinations were kindly made by Dr. W. J. Russell, F. R. S., of London, in specimens collected at Rothamsted, whilst the wheat and barley were still green, and actively growing.

It will be seen, in the first place, that the separated leguminous herbage of hay contained a much higher percentage of nitrogen in its dry matter than the separated gramineous herbage; and that, with the much higher percentage of nitrogen in the leguminous herbage, there was also a much higher proportion of chlorophyl.

Next, it is to be observed that the wheat plant on plot 10a, manured with ammonium-salts alone, shows a much higher percentage of nitrogen than that of plot 7, with the same amount of ammonium-salts, but with mineral manure in addition. The high proportion of chlorophyll again goes with the high nitrogen percentage; but the last column of the table shows that on plot 10a, with ammonium-salts without mineral manure, with the high percentage of nitrogen and high proportion of chlorophyll in the green produce, there was eventually a very much less assimilation of carbon. The result is exactly similar in the case of the barley; plot 1a being manured with ammonium-salts alone, and plot 4a with the same ammonium-salts and mineral manure in addition.

It is evident that the chlorophyll formation has a close connection with the amount of nitrogen assimilated; but that the carbon assimilation is not in proportion to the chlorophyll formed, if there is not a sufficiency of the necessary mineral constituents available. No doubt there had been as much or more of both nitrogen assimilated, and chlorophyll formed, over a given area, where the mineral as well as the nitrogenous manure had been applied; the lower *proportion* of both in the dry matter being due to the greater assimilation of carbon, and consequent greater formation of non-nitrogenous substance.

The next point to consider is, what is the effect of the unrecovered amount of nitrogen on succeeding crops. This is illustrated by the results in the colored columns of Table I. In the table mineral manure is indicated by blue, nitrogen as ammonium-salts by yellow, and a mixture of the two by green. Plot 5 has been manured continuously for thirty-two years with mineral manure alone; whilst plots 17 and 18 each received mineral manure, and a quantity of ammonium-salts containing 86 lbs. of nitrogen alternately. Thus we are able, for every year, to compare a plot manured with minerals, succeeding a previous application of ammonium-salts, with a plot receiving mineral manure alone yearly. It is seen that, in every case, the application of nitrogen has given a greatly increased yield, frequently doubling that of the plot with mineral manure alone. Again, in every case, the yield of the succeeding year, when the mineral manure was applied, was reduced approximately to that of the plot continuously treated with minerals alone. A glance down the alternately blue and yellow columns of plots 17 and 18, and a comparison with the blue column of plot 5, will bring these results strikingly to view. A comparison of the averages of the periods of four, eight, sixteen, and thirty-two years of this treatment clearly shows the essential identity of the results of the continuous and the alternate treatment with mineral manures. The averages for the thirty-two years show an increase in the yield of the mineral-manure years after ammonia, over the yield of plot 5, of only  $\frac{3}{8}$  of a bushel per acre per annum in a crop of between fifteen and sixteen bushels. The non-effect, or the absence, of residual nitrogen applied in the form of ammonium-salts, is evident. In other words, nitrogen as ammonium-salts applied in any one year is practically exhausted that year, in the crop or otherwise, leaving practically none for subsequent action.

Again, plot 16, for thirteen years, from 1852 to 1864 inclusive, received annually mixed mineral manure and ammonium-salts, containing a double quantity (172 lbs.) of nitrogen; and since that time, for nineteen years (1864-1883), it has been left unmanured. During the thirteen years of heavy manuring there was a large yield, in two cases exceeding

fifty bushels, with an average for the thirteen years of  $39\frac{1}{2}$  bushels. The first three years during which no manure was applied, the average yield was only  $21\frac{1}{2}$  bushels, a decrease of nearly one-half, followed in the succeeding periods of four years each by average yields of  $17\frac{5}{8}$ , 12,  $9\frac{7}{8}$ , and  $13\frac{3}{4}$  bushels; against, for the corresponding periods on plot 3, continuously without manure,  $8\frac{1}{2}$ ,  $13\frac{3}{4}$ ,  $10\frac{5}{8}$ , and  $12\frac{1}{2}$  bushels. Or, taking the average of the nineteen years of yield without manure on plot 16, we have  $14\frac{5}{8}$  bushels, against, over the same years,  $13\frac{1}{8}$  bushels, on plot 5, with mineral manures only, since 1852, and  $11\frac{3}{8}$  bushels on plot 3, unmanured since 1839. It is fair to presume, moreover, that some of the greater yield of plot 16, from 1864-1883, over that of plot 3, is due to the residue of the mixed mineral manure, which, as will be seen further on, has some effect on succeeding crops.

If, as the above results have demonstrated, there is practically no residue from previous application of ammonium-salts, the question arises, What becomes of the nitrogen of the manure not taken up by the crop? This point is illustrated by the results given in Table V. The plots there tabulated all received the same amount of nitrogen in manure, with differing mineral manures, and they are given in the order of their average annual increased yield of nitrogen in the crops over plot 5, with mineral manure alone. The first column shows the estimated average annual increased yield of nitrogen per acre in the crops; the second, the estimated annual loss of nitrogen as nitric acid by drainage; the third, the estimated annual excess of nitrogen in the surface-soil over that on plot 5 with the mineral manure alone; and the last column shows the relation which that excess in the soil bears to 100 increased yield of nitrogen in the crops.

The plots were manured as follows:

- Plot 10 — Amm.-salts = 86 lbs. N.  
 “ 11 — Amm.-salts = 86 lbs. N., and superphosphate.  
 “ 12 — Amm.-salts = 86 lbs. N., superphosphate and soda.  
 “ 13 — Amm.-salts = 86 lbs. N., superphosphate and potash.  
 “ 14 — Amm.-salts = 86 lbs. N., superphosphate and magnesia.  
 “ 7 — Amm.-salts = 86 lbs. N., and mixed mineral manure.  
 “ 9 — Nitrate of soda = 86 lbs. N., and mixed mineral manure.

TABLE V.

## BROADBALK EXPERIMENTAL WHEAT-FIELD.

Estimated Nitrogen per acre per annum.

Plots.	In Crops over Plot 5.	Lost by Drainage over Plot 5.	In surface soil 9 inches deep over Plot 5.	Excess in surface soil to 100 increase in Crop.
	lbs.	lbs.	lbs.	lbs.
10	12.4	31.2	4.8	38.7
11	17.7	28.5	11.6	65.5
12	22.2	24.5	14.6	65.8
13	23.4	25.6	17.8	76.1
14	24.1	27.5	15.5	64.3
7	25.9	19.0	19.3	74.5
9	26.5	23.7	18.5	71.2

It is seen that the increased yield of nitrogen in the crops varied exceedingly with the same amount supplied in manure, according to the condition as to supply of mineral constituents. Plot 10, with the ammonium-salts alone, gives the smallest increased yield of nitrogen in the crop; and plots 7 and 9, with the most complete mineral manure, each more than twice as much; the other plots giving intermediate amounts.

The order of the estimated loss of nitrogen by drainage is almost the converse of that of the increased yield in the crops. Plot 10, which gives the least increased yield in the crop, shows the greatest loss by drainage; and plots 7 and 9, which yield the greatest increase in the crop, show the least loss by drainage.

The excess in the soils (over plot 5) is obviously much more in the order of the increased yield in the crops. Plot 10, with the least in the increase of crop and the most in the drainage, shows the least excess in the soil; whilst plots 7 and 9, with the greatest increased yield in the crop, and the least loss by drainage, show the greatest excess in the soil.

It is clear, therefore, that whilst the excess in the soil has no direct relation to the amount supplied in the manure, it has a very obvious relation to the increased yield in the crop; in other words, to the amount of growth. The last column of the table brings this out more clearly. Excepting in the case of plot 10, with the ammonium-salts alone, there is a general uniformity in the proportion of the excess in the soil over plot 5 to the increased yield in the crop over plot 5; and the variations, such as they are, have an obvious connection with the conditions of growth. Thus plots 11, 12, and 14, all with a deficient supply of potash, show approximately equal proportions retained in the soil for 100 of increase in the crop. Plots 13, 7, and 9, again, all with liberal supplies of potash, show higher, but approximately equal, proportions retained in the surface-soil for 100 of increased yield in the crop.

Upon the whole, it is obvious that the relative excess of nitrogen in the soils of the different plots is little, if at all, due to the direct retention by the soil of the nitrogen of the manure, but it is almost exclusively dependent on the difference in amount of the residue of the crops — of the stubble and roots, and perhaps of weeds.

This leads to the consideration of the actual differences in the crop with equal nitrogen supply and different mineral supply. This is illustrated by the results in Table VI., which shows the effects of mineral manures alone, of ammonium-salts alone, and of ammonium-salts with different mineral manures.

TABLE VI.

*Wheat grown for forty years in succession on the same land.  
Broadbalk Field, Rothamsted.*

Results showing the effects of Mineral Manures alone, and when used in addition to Ammonium-Salts.

*Quantities per acre. Produce: Dressed Grain in bushels.*

400 lbs. Ammonium-Salts = 86 lbs. Nitrogen per acre per annum.								
Plot No—	Mixed Mineral Manure Alone.	Alone, 1852 and since. Prev'ly Min. Man. 1844, '48 and '50. Am.-Salts 1845-51.	Alone, 1852 and since. Prev'ly Min. Man. 1844, '48 and '50. Am.-Salts 1845, '7, '8, '9 and '51.	And Superphosphate.	And Superphosphate and Sulphate of Soda.	And Superphosphate and Sulphate of Potash.	And Superphosphate and Sulphate of Magnesia.	And Superphosphate and Sulphates of Potash, Soda and Magnesia.
Plot No—	Plot 5	Plot 10a	Plot 10b	Plot 11	Plot 12	Plot 13	Plot 14	Plot 7
Harvests. 8 yrs. '44,'51	Bushels. 29	Bushels. 26	Bushels. 24 $\frac{3}{8}$	Bushels. 28 $\frac{1}{2}$	Bushels. 28 $\frac{1}{8}$	Bushels. 27 $\frac{7}{8}$	Bushels. 27 $\frac{1}{4}$	Bushels. 29 $\frac{1}{4}$
1852	16 $\frac{1}{2}$	21 $\frac{1}{8}$	22 $\frac{1}{2}$	23 $\frac{1}{4}$	24 $\frac{1}{2}$	24	24 $\frac{3}{4}$	26 $\frac{3}{4}$
1853	10 $\frac{1}{2}$	10	15 $\frac{1}{2}$	18 $\frac{1}{2}$	22 $\frac{1}{2}$	23	22 $\frac{3}{4}$	23 $\frac{3}{4}$
1854	24 $\frac{1}{4}$	34 $\frac{3}{8}$	39 $\frac{1}{4}$	43 $\frac{7}{8}$	45 $\frac{1}{2}$	44 $\frac{1}{2}$	44 $\frac{3}{4}$	45 $\frac{1}{2}$
1855	18 $\frac{1}{4}$	20	28 $\frac{1}{4}$	21 $\frac{3}{4}$	31 $\frac{1}{4}$	30 $\frac{3}{4}$	31 $\frac{1}{2}$	33
1856	19 $\frac{1}{2}$	24 $\frac{1}{4}$	27 $\frac{3}{4}$	31 $\frac{1}{4}$	33 $\frac{3}{8}$	31 $\frac{1}{2}$	34 $\frac{1}{2}$	36 $\frac{7}{8}$
1857	23 $\frac{1}{2}$	29 $\frac{1}{2}$	34 $\frac{1}{2}$	39 $\frac{1}{2}$	43 $\frac{1}{4}$	43 $\frac{1}{2}$	45 $\frac{1}{2}$	48 $\frac{1}{2}$
1858	18 $\frac{1}{2}$	22 $\frac{1}{2}$	27 $\frac{3}{4}$	32	37 $\frac{1}{2}$	37 $\frac{1}{4}$	38 $\frac{3}{8}$	39 $\frac{1}{2}$
1859	20 $\frac{1}{2}$	19	25 $\frac{3}{8}$	27 $\frac{3}{8}$	34 $\frac{1}{4}$	34 $\frac{1}{2}$	34 $\frac{1}{2}$	34 $\frac{1}{2}$
1860	15 $\frac{1}{2}$	15 $\frac{1}{2}$	18 $\frac{1}{2}$	22 $\frac{3}{8}$	27 $\frac{1}{2}$	26 $\frac{1}{2}$	27 $\frac{1}{4}$	27 $\frac{3}{4}$
1861	15 $\frac{1}{2}$	12 $\frac{1}{2}$	16	24 $\frac{1}{2}$	32 $\frac{1}{2}$	34 $\frac{1}{2}$	33 $\frac{1}{2}$	35
1862	17 $\frac{1}{2}$	23 $\frac{1}{2}$	24 $\frac{1}{2}$	26 $\frac{1}{2}$	33 $\frac{3}{4}$	32 $\frac{1}{2}$	31 $\frac{1}{4}$	35 $\frac{1}{2}$
1863	19 $\frac{1}{2}$	39 $\frac{1}{2}$	43 $\frac{3}{8}$	45 $\frac{1}{4}$	54	53 $\frac{1}{4}$	54	53 $\frac{1}{2}$
1864	16 $\frac{1}{2}$	32 $\frac{1}{4}$	36 $\frac{1}{4}$	36 $\frac{1}{2}$	44 $\frac{1}{2}$	43 $\frac{1}{4}$	41 $\frac{1}{2}$	45 $\frac{3}{4}$
1865	14 $\frac{1}{4}$	25 $\frac{1}{4}$	30 $\frac{1}{2}$	27 $\frac{1}{2}$	34 $\frac{1}{2}$	37 $\frac{1}{2}$	36 $\frac{1}{2}$	40 $\frac{1}{4}$
1866	13 $\frac{1}{4}$	26 $\frac{1}{4}$	28 $\frac{1}{2}$	28	28 $\frac{1}{4}$	24 $\frac{3}{4}$	28	29 $\frac{1}{2}$
1867	9 $\frac{1}{4}$	18 $\frac{1}{4}$	19 $\frac{3}{8}$	22 $\frac{1}{2}$	24 $\frac{1}{2}$	23 $\frac{1}{2}$	22 $\frac{3}{4}$	22 $\frac{1}{2}$
1868	17 $\frac{1}{2}$	24 $\frac{1}{4}$	27 $\frac{3}{4}$	33 $\frac{1}{2}$	39 $\frac{1}{2}$	39 $\frac{1}{4}$	41 $\frac{1}{2}$	39 $\frac{1}{2}$
1869	15 $\frac{1}{2}$	20 $\frac{1}{4}$	19 $\frac{1}{2}$	22 $\frac{1}{4}$	27 $\frac{1}{4}$	27 $\frac{1}{4}$	27 $\frac{1}{4}$	28 $\frac{3}{4}$
1870	18 $\frac{1}{2}$	21 $\frac{3}{4}$	23 $\frac{1}{4}$	25 $\frac{1}{4}$	35 $\frac{1}{4}$	37	35 $\frac{3}{4}$	40 $\frac{1}{2}$
1871	11 $\frac{1}{2}$	10 $\frac{3}{8}$	10	11	21 $\frac{1}{2}$	30 $\frac{1}{2}$	24 $\frac{1}{4}$	22 $\frac{1}{4}$
1872	12 $\frac{3}{4}$	18	18 $\frac{3}{4}$	27 $\frac{1}{4}$	29 $\frac{1}{4}$	29 $\frac{1}{2}$	30 $\frac{3}{8}$	29 $\frac{3}{4}$
1873	12 $\frac{3}{4}$	19 $\frac{1}{2}$	20 $\frac{3}{8}$	19 $\frac{1}{4}$	22 $\frac{1}{2}$	23 $\frac{1}{2}$	24 $\frac{1}{2}$	22
1874	13	25 $\frac{1}{4}$	27 $\frac{1}{4}$	32 $\frac{1}{2}$	39 $\frac{1}{2}$	37 $\frac{1}{2}$	36 $\frac{1}{2}$	39 $\frac{1}{2}$
1875	9 $\frac{1}{4}$	12 $\frac{3}{4}$	14 $\frac{3}{8}$	18	25 $\frac{1}{4}$	27 $\frac{1}{2}$	26 $\frac{1}{4}$	25 $\frac{1}{2}$
1876	10 $\frac{1}{2}$	12 $\frac{1}{2}$	14 $\frac{1}{2}$	14 $\frac{3}{8}$	19 $\frac{1}{2}$	25 $\frac{1}{2}$	22 $\frac{1}{2}$	23 $\frac{1}{2}$
1877	11 $\frac{1}{2}$	17 $\frac{1}{4}$	18 $\frac{1}{4}$	17 $\frac{1}{2}$	17 $\frac{1}{4}$	18 $\frac{1}{4}$	18 $\frac{1}{2}$	19 $\frac{1}{2}$
1878	14 $\frac{3}{4}$	27 $\frac{3}{8}$	29 $\frac{1}{2}$	29 $\frac{1}{2}$	29 $\frac{1}{4}$	29 $\frac{1}{2}$	32 $\frac{1}{4}$	31 $\frac{1}{4}$
1879	5 $\frac{1}{2}$	4	4 $\frac{1}{2}$	11 $\frac{1}{2}$	14	16	16 $\frac{1}{4}$	16 $\frac{1}{4}$
1880	17 $\frac{1}{2}$	10 $\frac{1}{2}$	13 $\frac{1}{2}$	25 $\frac{3}{4}$	29 $\frac{1}{2}$	33	31	34 $\frac{1}{2}$
1881	12 $\frac{3}{4}$	18 $\frac{1}{4}$	19 $\frac{1}{4}$	21 $\frac{1}{2}$	23 $\frac{3}{4}$	28 $\frac{1}{4}$	27 $\frac{1}{2}$	26 $\frac{1}{2}$
1882	12 $\frac{1}{2}$	23 $\frac{3}{4}$	26 $\frac{1}{2}$	30 $\frac{3}{4}$	34 $\frac{1}{2}$	32 $\frac{1}{2}$	34 $\frac{1}{2}$	35 $\frac{3}{4}$
1883	15 $\frac{1}{4}$	17 $\frac{1}{2}$	18 $\frac{1}{2}$	26 $\frac{3}{8}$	30 $\frac{3}{4}$	34 $\frac{1}{2}$	33 $\frac{1}{2}$	36 $\frac{1}{2}$
AVERAGES.								
4 yrs. '52,'55	17 $\frac{1}{2}$	21 $\frac{1}{2}$	26 $\frac{1}{4}$	26 $\frac{3}{4}$	31 $\frac{1}{4}$	30 $\frac{1}{2}$	30 $\frac{1}{2}$	32 $\frac{1}{4}$
4 yrs. '56,'59	20 $\frac{3}{4}$	23 $\frac{1}{2}$	28 $\frac{1}{2}$	32 $\frac{1}{2}$	37 $\frac{1}{2}$	36 $\frac{1}{2}$	37 $\frac{1}{2}$	38 $\frac{1}{2}$
4 yrs. '60,'63	17 $\frac{1}{4}$	22 $\frac{1}{2}$	25 $\frac{3}{4}$	29 $\frac{1}{2}$	37	36 $\frac{1}{2}$	36 $\frac{1}{2}$	38
4 yrs. '64,'67	13 $\frac{1}{2}$	25 $\frac{1}{2}$	25 $\frac{1}{2}$	28 $\frac{1}{2}$	33	32 $\frac{1}{4}$	32 $\frac{1}{4}$	34 $\frac{1}{2}$
4 yrs. '68,'71	16	19 $\frac{1}{2}$	20	23	30 $\frac{1}{2}$	33 $\frac{3}{4}$	32 $\frac{3}{4}$	33 $\frac{3}{4}$
4 yrs. '72,'75	12	18 $\frac{1}{2}$	20 $\frac{1}{4}$	24 $\frac{1}{2}$	29 $\frac{1}{4}$	29 $\frac{1}{2}$	29 $\frac{1}{2}$	29 $\frac{1}{4}$
4 yrs. '76,'79	10 $\frac{1}{2}$	15 $\frac{1}{2}$	16 $\frac{1}{2}$	18 $\frac{1}{4}$	20	22 $\frac{1}{4}$	22 $\frac{1}{4}$	22 $\frac{1}{2}$
4 yrs. '80,'83	14 $\frac{3}{4}$	17 $\frac{1}{2}$	19 $\frac{1}{2}$	26	29 $\frac{1}{2}$	31 $\frac{1}{2}$	31 $\frac{1}{2}$	33 $\frac{1}{4}$
8 yrs. '52,'59	19	22 $\frac{1}{2}$	27 $\frac{1}{2}$	29 $\frac{1}{2}$	34 $\frac{1}{4}$	33 $\frac{3}{4}$	34 $\frac{1}{4}$	35 $\frac{1}{2}$
8 yrs. '60,'67	15 $\frac{1}{4}$	24	27 $\frac{1}{4}$	29 $\frac{1}{2}$	35	34 $\frac{1}{2}$	34 $\frac{1}{2}$	36 $\frac{1}{4}$
8 yrs. '68,'75	14	19	20 $\frac{1}{2}$	23 $\frac{1}{2}$	30	31 $\frac{1}{2}$	30 $\frac{7}{8}$	31
8 yrs. '76,'83	12 $\frac{1}{2}$	16 $\frac{3}{4}$	18 $\frac{1}{2}$	22 $\frac{1}{2}$	24 $\frac{1}{2}$	27	27	28
16 yrs. '52,'67	17 $\frac{1}{2}$	23 $\frac{1}{4}$	27 $\frac{1}{2}$	29 $\frac{1}{2}$	34 $\frac{1}{2}$	34	34 $\frac{1}{2}$	35 $\frac{1}{2}$
16 yrs. '68,'83	13 $\frac{1}{2}$	17 $\frac{1}{4}$	19 $\frac{1}{2}$	22 $\frac{1}{2}$	27 $\frac{1}{2}$	29 $\frac{1}{4}$	28 $\frac{1}{2}$	29 $\frac{1}{2}$
32 yrs. '52,'83	15 $\frac{1}{4}$	20 $\frac{1}{2}$	23 $\frac{1}{4}$	26 $\frac{1}{2}$	31	31 $\frac{1}{2}$	31 $\frac{1}{2}$	32 $\frac{3}{4}$
	5	10a	10b	11	12	13	14	7

For the thirty-two years,—1852 to 1883 inclusive,—each of the eight differently manured plots received the same manure each year. I will only call special attention to the average yields over periods of sixteen and thirty-two years.

Plot 5, treated with mineral manure only, gave, during the first sixteen years, an average yearly yield of  $17\frac{3}{8}$  bushels per acre, during the second sixteen years  $13\frac{3}{8}$  bushels, and during the whole period of thirty-two years  $15\frac{1}{4}$  bushels.

Plot 10a, treated with ammonium-salts only, gave, during the first sixteen years, an average yearly yield of  $23\frac{3}{8}$  bushels per acre, during the second sixteen years  $17\frac{3}{4}$  bushels, and during the thirty-two years an average of  $20\frac{1}{2}$  bushels. Thus, ammonium-salts alone produced much more than mineral manure alone.

On plot 10b, previous to 1852,—in the years 1844, 1848, and 1850,—mineral manures had been applied, in the other years previous to 1852 (excepting in 1846, when it was unmanured), and subsequently, ammonium-salts only. The effect of the residue of the previously applied mineral manures is apparent on comparison with the yields on 10a.

On plot 10b we find, during the first period of sixteen years, an average yearly yield of  $27\frac{3}{8}$  bushels per acre, against  $23\frac{3}{8}$  bushels on 10a; during the second period of sixteen years  $19\frac{1}{8}$  bushels, against  $17\frac{3}{4}$  on 10a; and during the thirty-two years, an average yearly yield of  $23\frac{1}{4}$  bushels, against only  $20\frac{1}{2}$  on 10a.

Plot 11, with superphosphate but no potash, in addition to the ammonium-salts, gave, during the first sixteen years, an average yearly yield of  $29\frac{3}{8}$  bushels per acre, during the second sixteen years  $22\frac{7}{8}$  bushels, and during the thirty-two years  $26\frac{7}{8}$  bushels.

On plot 12, in addition to the ammonium-salts, superphosphate and sulphate of soda were applied; but potash had been applied prior to 1852. The first sixteen years produced an average yearly yield of  $34\frac{5}{8}$  bushels per acre, the second sixteen years of  $27\frac{1}{2}$  bushels, and the whole thirty-two years of 31 bushels.

On plot 13, the ammonium-salts, superphosphate, and sulphate of potash were applied, and the average annual produce was, over the first sixteen years 34 bushels, over the second sixteen years  $29\frac{1}{4}$ , and over the thirty-two years  $31\frac{5}{8}$  bushels.

On plot 14, besides the ammonium-salts and superphosphate, sulphate of magnesia was applied, and some potash had been applied prior to 1852. The average annual produce was, over the first sixteen years  $34\frac{3}{8}$  bushels, over the second sixteen years  $28\frac{7}{8}$  bushels, and over the thirty-two years  $31\frac{5}{8}$  bushels.

On plot 7, in addition to the ammonium-salts, superphosphate and the sulphates of potash, soda and magnesia, were applied, and gave, during the first sixteen years, an average yearly yield of  $35\frac{7}{8}$  bushels per acre, during the second sixteen years of  $29\frac{1}{2}$  bushels, and during the whole thirty-two years of  $32\frac{3}{4}$  bushels.

Thus, not only the effect upon the yield of wheat of a direct supply, but of a residue from long previous applications of potash, is very noticeable. This is rendered more obvious by reference to the following table (VII.), in which the pounds per acre of potash and phosphoric acid removed during two periods of ten years each, in the total produce,

and in the grain alone, of the plots last referred to, and some others are given.

TABLE VII.

Potash and Phosphoric Acid in Grain, and in Total Produce.

Ten years, 1852-'61, and ten years, 1862-'71.

PER ACRE IN POUNDS.

	POTASH.				PHOSPHORIC ACID.			
	1852-'61.		1862-'71.		1852-'61.		1862-'71.	
	TOTAL GRAIN PRODUCE.		TOTAL GRAIN PRODUCE.		TOTAL GRAIN PRODUCE.		TOTAL GRAIN PRODUCE.	
2	52.6	11.8	53.5	12.4	26.5	19.6	27.3	20.1
3	19.0	5.5	15.3	4.9	10.8	8.2	9.7	7.5
5	26.6	6.6	21.1	5.7	14.7	10.5	12.3	8.8
10a	27.2	7.1	23.1	7.7	13.0	9.6	13.4	10.4
10b	33.3	8.5	25.0	8.7	16.0	12.2	14.8	12.0
11	30.9	9.3	26.0	8.8	19.8	14.9	18.0	13.6
12	45.4	11.4	37.8	11.4	23.2	17.7	21.8	17.0
13	53.2	11.3	55.2	12.2	22.9	17.7	23.3	18.2
14	49.8	11.3	39.1	11.6	22.9	17.9	22.4	17.6
7	56.0	11.9	53.0	12.3	23.8	18.4	23.4	18.5

I will illustrate this point by referring only to the potash. Plots 3, 10a, 10b, and 11 show a deficiency of potash in both grain and total produce compared with the amounts in the produce of plots 2, 12, 13, 14 and 7, on all of which there was a sufficiency, or more or less excess, of potash available. On comparison of these results with the manuring of the plots, we find that in every case the increase of potash in the total crop depends either on a direct annual potash supply, or on a residue from previous applications. The first ten years shows more potash in the total produce with the direct supply (13 and 7) than with the residue (12 and 14); but the amount in the grain is essentially the same in each case. In the second ten years there is a greater difference in the amounts of potash in the total produce between the plots having the direct and those having only the residual supply; whilst there is scarcely any difference in the amounts in the grain, but such as it is, it is in accordance with the conditions of supply. Hence it is evident that whilst the plant in its vegetative stages assimilates according to the available supply,—it may be in excess of actual need,—if there is no deficiency, the composition of the final product—the seed—is essentially the same.

We have thus traced the effects of exhaustion, of full manuring, and of nitrogenous and non-nitrogenous manures on one particular soil. It has been seen how very different is the effect of one and the same manuring in different seasons, but the real extent of this variation is more clearly brought out in Table VIII., which shows the best, the worst, and the average produce, over a period of thirty-two years, under very opposite conditions as to manuring.

TABLE VIII.

*Wheat year after year on the same land. Broadbalk Field, Rothamsted.*

Produce of the best season, 1863; the worst season, 1879; and average of 32 years, 1852-1883.

Plot No.	Description of Manures—Quantities per acre.	Dressed Grain per acre—Bushels.			
		Best Season 1863	Worst Season 1879	Diff.	Average 32 yrs. 1852-'83
3	Unmanured.....	17¼	4¾	12½	13½
2	Farm-yard Manure.....	44	16	28	33½
5	Mixed Mineral Manure, alone.....	19%	5%	14	15¼
6	Mixed Min. Man. and 200 lbs. Amm.-Salts = 43 lbs. Nit.	39%	10½%	29%	24%
7	Mixed Min. Man. and 400 lbs. Amm.-Salts = 86 lbs. Nit.	53%	16¾	37%	32%
9	Mixed Min. Man. and 550 lbs. Nitra. Soda = 86 lbs. Nit.	55%	22	33%	36¾
8	Mixed Min. Man. and 600 lbs. Amm. Salts = 129 lbs. Nit.	55¾	20%	35%	36¾

We will confine our attention to the amount of dressed grain per acre in bushels. The difference in yield of the various plots in the best and worst of the thirty-two seasons is very marked. The unmanured, the mineral manured, and the heavily nitrogeous manured plots, all suffered severely. In most cases the difference approaches, and in two cases (Plots 6 and 7 mixed mineral manure, together with 200 and 400 pounds of ammonium-salts, respectively furnishing 43 and 86 pounds of nitrogen) it actually exceeds the average produce of the plots. From these facts we see how easy it is to form wrong conclusions as to the effects of different manures, if experiments are conducted in only one season or in only a few seasons, and if the characters of the seasons are not studied.

Not only season, but soil and locality must exercise an influence. The Rothamsted results are obtained on one description of soil, and in one locality only. Reference to the following table (IX.) shows the results obtained in experiments conducted at Rothamsted during the same eight years, but in two fields; at the same place in one field for thirty-two years; at Woburn, for seven years; at Holkham, Norfolk, for three years; and at Rodmersham, Kent, for four years. Thus, the experiments were made on very various soils, under various conditions from previous treatment, and in various seasons, yet the general characters of the results are accordant.

TABLE IX.

*Results of Experiments on the growth of Wheat by different Manures, on different Soils, in different Localities, and in different Seasons.*

MANURES. QUANTITIES PER ACRE.	DRESSED GRAIN PER ACRE—BUSHELS. AVERAGE ANNUAL RESULTS.					
	Rothamsted.			Woburn, Beds, 7 years. 1877-'83.	Holkham, Norfolk, 3 years. 1852-'54.	Rodmers- ham, Kent 4 years. 1856-'59.
	8 years— 1856-'63.		32 years— 1852-'83.			
	Broadbalk Field.	Hoos Field.	Broadbalk Field.			
Unmanured.....	16	15	13½	15%	18	25%
Mixed Mineral Manure, alone	19	16½	15½	16%	19½	28½
Amm.-Salts, alone=86 lbs. N.	23¼	26%	20%	23% 1)	27¼	31½
Mixed Mineral Manure, and Ammonium-Salts = 86 lbs. N. }	38½	37%	32¾	37%	32%	33½

(1) By Ammonium-Salts = only 43 lbs. N.

Not only is there general accordance in the character of the results in different localities, when the averages of a number of years are taken, but the non-effect of the residue from previous application of ammonium-salts is as marked in the sandy soil at Woburn as in the very different soil at Rothamsted. Reference to Table X. will illustrate this. Stackyard field, Woburn, received mineral manure, and ammonium-salts=86 lbs. nitrogen, for five successive years. The field was then divided, one portion receiving the same manure as before, and the other the mixed mineral manure, but no nitrogen. In the next year, 1883, the portion which had received nitrogen in the previous year received mineral manures only, and conversely the other portion, which had received mineral manure only in 1882, received both mineral manure and ammonium-salts. It is seen that in each year, 1882 and 1883, the portion which received the nitrogenous manure yielded large crops ( $43\frac{1}{2}$  and  $45\frac{3}{4}$  bushels); whereas, the portion on which mineral manures alone succeeded ammonium-salts and large crops, yielded very small crops— $13\frac{1}{4}$  and  $17\frac{1}{4}$  bushels, respectively, against  $14\frac{7}{8}$  and  $17\frac{1}{4}$  bushels on the plot where the same mineral manures were used year after year. It is thus seen that there was no available and effective residue where the ammonium-salts had previously been applied. It may be stated, however, that in 1884 there was notable effect from unexhausted residue of nitrogenous manure; the explanation probably being that there had been very little rain, and consequently very little loss by drainage during the winter of 1883-4.

TABLE X.

*Wheat grown year after year on the same land.  
Stackyard Field, Woburn.*

Harvests.	Dressed Grain. Bushels.	
1877	43%	
1878	27	
1879	31 $\frac{1}{4}$	
1880	28%	
1881	43%	
1882	(1) $13\frac{1}{4}$	(2) $43\frac{1}{2}$
1883	(2) $45\frac{3}{4}$	(1) $17\frac{1}{4}$

(1) Mixed Mineral Manure alone. (2) Mix. Min. Man. and Ammonium-Salts = 86 lbs. N.

Having illustrated the soil conditions necessary for the growth of wheat, it will be well to call attention to one practical application of these long-continued field experiments. For thirty-two years (1852-83) an estimate has been made of the average produce of wheat per acre in the United Kingdom, based upon the yield at Rothamsted on the unmanured, the farm-yard manured, and three of the artificially manured plots taken as one. From this the total yield of the country has been calculated; to this the imports have been added, and the quantity required for seed deducted, the final figure showing the total amount available for consumption, and from this the consumption per head of the population has been reckoned. It may be said at once that these results proved to be very near the truth. But the point of interest to a wheat-growing and wheat-exporting country like America is, the evidence which the results afford as to the constantly increasing requirements of a largely importing country like Great Britain.

The following table (XI.) shows that during the thirty-two years, 1852-3, to 1883-4 inclusive, the area under wheat in the United Kingdom has been reduced by about one-third. The average yield per acre is estimated at 28 bushels; but owing to recent bad seasons, the average for the whole period of thirty-two years was only 27 bushels, that for the first sixteen years having been 28  $\frac{1}{4}$ , but that for the second sixteen years only 25  $\frac{3}{4}$ . Thus there has not only been a reduction in area under cultivation, but in yield per acre, also; this, however, is probably temporary, whilst the reduction in area will doubtless continue.

TABLE XI.

*Particulars of Home Produce, Imports, and Consumption of Wheat, in the United Kingdom—32 years, 1852-3 to 1883-4.*

Harvest years, Sept. 1 to Aug. 31.	Estimated Home Produce.			Available for consumption.			Available for Consumption per head.		
	Area under Crop.	Aver'g yield per Acre.	Total Home Produce.	Homeproduce less 2 $\frac{1}{4}$ bush's per acre for seed.	Imports less Exports.	Total.	From Home Produce.	From Imports.	Total.
1852-3	4,058,731	22 $\frac{1}{2}$	11,574,982	10,433,464	5,902,000	16,335,464	3,03	1,71	4,74
1853-4	4,013,963	20 $\frac{3}{4}$	10,466,473	9,337,546	6,092,000	15,429,546	2,70	1,76	4,46
1854-5	4,036,969	34 $\frac{3}{4}$	17,563,140	16,427,742	2,983,000	19,410,742	4,73	0,85	5,58
1855-6	4,076,447	27 $\frac{1}{2}$	13,922,801	12,776,300	3,265,000	16,041,300	3,65	0,93	4,58
1856-7	4,213,651	27	14,192,543	13,007,453	4,112,584	17,120,037	3,70	1,16	4,86
1857-8	4,185,974	33 $\frac{1}{2}$	17,321,221	16,143,915	5,795,687	21,939,602	4,56	1,63	6,19
1858-9	4,131,822	31 $\frac{1}{2}$	16,909,949	15,147,874	4,555,670	19,703,544	4,24	1,28	5,52
1859-60	4,019,725	26 $\frac{1}{2}$	13,135,124	12,004,575	4,516,332	16,520,907	3,34	1,25	4,59
1860-1	3,992,657	22 $\frac{1}{2}$	11,078,948	9,956,012	10,023,968	19,979,980	2,75	2,77	5,52
1861-2	3,898,177	25 $\frac{1}{2}$	12,271,546	11,175,183	9,099,455	20,274,638	3,06	2,49	5,55
1862-3	3,823,947	29 $\frac{1}{4}$	13,957,554	12,882,069	9,205,086	22,087,155	3,51	2,51	6,02
1863-4	3,698,629	38 $\frac{3}{4}$	17,922,048	16,881,807	6,991,270	23,873,077	4,57	1,89	6,46
1864-5	3,685,493	35 $\frac{1}{4}$	16,216,328	15,179,783	5,500,705	20,680,488	4,08	1,48	5,56
1865-6	3,646,691	30 $\frac{3}{4}$	13,975,936	12,950,305	7,313,026	20,263,331	3,47	1,95	5,42
1866-7	3,649,584	25 $\frac{1}{2}$	11,485,091	10,458,645	7,633,033	18,091,678	2,78	2,02	4,80
1867-8	3,628,910	21	9,566,522	8,545,890	9,015,543	17,561,433	2,25	2,38	4,63
1868-9	3,937,275	34	16,733,419	15,626,060	7,719,304	23,345,364	4,09	2,02	6,11
1869-70	3,976,147	27	13,419,496	12,301,205	9,921,526	22,222,731	3,20	2,58	5,78
1870-1	3,761,457	30	14,105,464	13,047,554	8,008,839	21,056,393	3,33	2,05	5,38
1871-2	3,818,848	24	11,456,544	10,382,493	9,316,600	19,699,093	2,62	2,35	4,97
1872-3	3,827,146	24	11,481,438	10,405,053	12,291,463	22,696,516	2,60	3,07	5,67
1873-4	3,658,815	22 $\frac{1}{2}$	10,290,417	9,261,375	11,301,316	20,562,691	2,29	2,80	5,09
1874-5	3,821,655	29 $\frac{1}{4}$	13,972,926	12,898,085	11,705,255	24,603,340	3,16	2,87	6,03
1875-6	3,503,709	22 $\frac{1}{2}$	10,018,418	9,033,000	13,860,079	22,893,079	2,19	3,36	5,55
1876-7	3,114,555	25	9,732,984	8,857,015	12,107,294	20,964,309	2,13	2,91	5,04
1877-8	3,311,859	26 $\frac{1}{2}$	10,970,533	10,039,073	14,408,628	24,447,701	2,38	3,42	5,80
1878-9	3,372,590	22	12,647,213	11,698,672	14,145,649	25,844,321	2,75	3,32	6,07
1879-80	3,047,752	15 $\frac{1}{2}$	5,905,020	5,047,840	16,409,933	21,457,773	1,17	3,82	4,99
1880-1	3,057,784	24 $\frac{1}{2}$	9,364,464	8,504,462	16,182,210	24,686,672	1,95	3,72	5,67
1881-2	2,960,066	24	8,880,198	8,047,679	17,200,108	25,247,787	1,83	3,91	5,74
1882-3	3,157,924	25 $\frac{1}{2}$	10,115,225	9,227,059	19,982,162	29,209,221	2,08	4,50	6,58
1883-4	2,707,949	28	9,477,822	8,616,211	15,815,878	24,432,089	1,92	3,53	5,45
AVERAGES.									
4 yrs. '52-'56	4,046,528	26 $\frac{1}{2}$	13,381,849	12,243,763	4,560,500	16,804,263	3,53	1,31	4,84
4 yrs. '56-'60	4,137,793	29 $\frac{1}{2}$	15,239,709	14,075,954	4,745,068	18,821,022	3,96	1,33	5,29
4 yrs. '60-'64	3,853,352	28 $\frac{1}{2}$	13,807,524	12,723,768	8,829,945	21,553,713	3,47	2,42	5,89
4 yrs. '64-'68	3,652,670	28	12,810,969	11,783,656	7,365,577	19,149,233	3,14	1,96	5,10
4 yrs. '68-'72	3,873,432	28 $\frac{3}{4}$	13,928,731	12,839,328	8,741,567	21,580,895	3,31	2,25	5,56
4 yrs. '72-'76	3,702,831	24 $\frac{1}{2}$	11,440,800	10,399,378	12,289,528	22,688,906	2,56	3,02	5,58
4 yrs. '76-'80	3,211,689	24 $\frac{1}{4}$	9,813,938	8,910,650	14,267,876	23,178,526	2,11	3,37	5,48
4 yrs. '80-'84	2,970,931	25 $\frac{1}{2}$	9,459,427	8,598,853	17,295,090	25,893,943	1,95	3,86	5,81
8 yrs. '52-'60	4,092,160	28	14,310,779	13,159,859	4,652,784	17,812,643	3,74	1,32	5,06
8 yrs. '60-'68	3,753,011	28 $\frac{1}{2}$	13,309,247	12,253,712	8,097,761	20,351,473	3,30	2,19	5,49
8 yrs. '68-'76	3,788,131	26 $\frac{3}{4}$	12,684,765	11,619,353	10,515,548	22,134,901	2,94	2,63	5,57
8 yrs. '76-'84	3,091,310	24 $\frac{1}{2}$	9,636,682	8,754,751	15,781,489	24,536,234	2,03	3,64	5,67
16 yrs. '52-'68	3,922,586	28 $\frac{1}{4}$	13,810,013	12,706,785	6,375,273	19,082,058	3,53	1,75	5,28
16 yrs. '68-'84	3,439,721	25 $\frac{3}{4}$	11,160,724	10,187,052	13,148,515	23,335,567	2,48	3,14	5,62
32 yrs. '52-'84	3,681,153	27	12,485,369	11,446,919	9,761,894	21,208,813	3,00	2,45	5,45

The great increase of population which has taken place within the period covered by the table has, of course, necessitated greatly increased consumption, and the comparison of the home production and the foreign importation, for successive periods, becomes of much interest. The table shows that the average annual consumption over the four successive periods of eight years each, increase as follows :

1852-3 to 1859-60,	Annual Consumption,	17,812,643	quarters.
1860-1 to 1867-8,	“	20,351,473	“
1868-9 to 1875-6,	“	22,134,901	“
1875-6 to 1883-4,	“	24,536,234	“

These amounts were supplied from home produce and importation as follows :

	HOME PRODUCTION.	IMPORTATION.
1852-3 to 1859-60,	13,159,859 quarters.	4,652,784 quarters.
1860-1 to 1867-8,	12,253,712 “	8,097,761 “
1868-9 to 1875-6,	11,619,353 “	10,515,548 “
1875-6 to 1883-4,	8,754,751 “	15,781,483 “

Thus, over the first eight years, only one-fourth of the wheat consumed was obtained from foreign sources, whilst over the last eight years, nearly two-thirds of the entire consumption were imported. It is probable that the home produce will still decline, consequent chiefly on reduction of area under cultivation; whilst with increase of population, imports must increase, and doubtless our supplies will be largely drawn from this continent.

It has been stated that, excluding recent bad seasons, the average yield of wheat per acre of the old arable soils of Great Britain, is twenty-eight bushels. Comparing this yield with that of the United States, as shown in the above table, we find, on the authority of the U. S. Census Bureau, that the general average of localities and years is 11.9 bushels per acre; a yield which is not equal to that of the continuously unmanured plot at Rothamsted, and which is considerably less than half the average yield of Great Britain under ordinary cultivation. This may be partly due to a shorter period of growth, and to rapid maturing, or in some localities to deficiency of rain; but it is probably largely also due to want of sufficient labor to clean the land, and to consequent luxuriance of weeds.

Referring to the table, we find the general averages of the different sections of the States ranging from 15.1 bushels per acre in New England, to 7.3 bushels in the South Atlantic and Eastern Gulf States. Even the North-west and Minnesota, including much prairie land, give very meager average produce for such rich soil. So long as wheat is grown on such lands under the conditions frequent, and indeed almost inevitable, in the case of new settlement,—that is, growing it year after year, with deficient cultivation, luxuriance of weeds, and the burning of the straw,—only low yields per acre can be expected. The result is due to the fact that, under such conditions, fertility is cheap and labor dear. But with increased density of population, more mixed agriculture must

be adopted. Stock must be kept, the farm kept freer from weeds, the straw used instead of being burnt, and the manure from it, and from the consumed food, returned to the land. Then, and not till then, will the fertility of the rich prairie soils be conserved, and not wasted, as is too often the case under the necessities of the first breaking up, and the sparse settlement, of the country. That your rich prairie soils can, and should, yield more produce than they do, is clear from the high yields obtained occasionally, under favorable conditions of cultivation.

TABLE XII

*Average yield per acre of Wheat and Indian Corn in the United States.*

(From Signal Service Reports.)

Six years—1875-1880.

WHEAT—BUSHELS.							
	1875	1876	1877	1878	1879	1880	GL.AV.
New England,.....	16.1	13.9	16.8	15.3	15.0	13.3	15.1
Middle States,.....	10.6	12.3	13.2	14.0	13.4	14.5	13.0
South Atlantic States,.....	7.5	6.8	9.0	6.5	8.0	6.2	7.3
East Gulf States,.....	9.0	6.7	7.2	7.1	8.1	5.6	7.3
West Gulf States,.....	14.8	11.5	11.1	13.2	7.7	7.7	11.0
Tennessee and Ohio Valley,.....	9.5	10.5	12.8	13.0	16.3	14.1	12.7
Upper Lake Region,.....	13.7	10.2	16.1	15.2	15.8	13.5	14.1
North West,.....	7.5	9.5	14.8	12.2	13.1	12.5	11.6
Minnesota,.....	17.0	8.5	18.5	12.0	12.3	13.2	13.6
California,.....	11.0	13.0	9.5	17.0	14.0	16.0	13.4
Average,.....	11.7	10.3	12.9	12.6	12.4	11.7	11.9

  

INDIAN CORN—BUSHELS.							
	1875	1876	1877	1878	1879	1880	GL.AV.
New England,.....	34.0	35.8	35.9	36.5	32.2	32.9	34.6
Middle States,.....	32.2	29.2	28.7	28.7	29.4	32.9	30.2
South Atlantic States,.....	12.0	11.5	11.3	11.4	10.7	10.2	11.2
East Gulf States,.....	15.0	13.3	13.2	12.1	14.3	13.4	13.6
West Gulf States,.....	21.4	23.2	22.6	24.2	15.9	24.0	21.9
Tennessee and Ohio Valley,.....	32.1	31.4	29.4	29.2	31.9	29.7	30.6
Upper Lake Region,.....	27.0	31.6	23.3	37.4	38.1	36.5	32.3
North West,.....	35.7	28.7	31.2	31.1	36.2	30.8	32.3
Minnesota,.....	29.2	25.4	29.0	38.1	35.0	35.0	32.0
California,.....	36.3	33.0	30.0	34.5	28.0	32.0	32.3
Average,.....	27.5	26.3	25.5	28.3	27.2	27.7	27.1

Turning to Indian Corn, Table XII. shows that the yield of that cereal is very much higher than that of wheat; and the yield of nitrogen per acre in those corn crops would doubtless be much greater than in the wheat crops of the same localities. This is probably in part due to the high condition of the soil under which the crop is generally grown, corn generally following clover in the rotation. It is, however, doubtless in part due to the growth of corn extending much further into the late summer and autumn, the period during which nitrification is the most active in the soil, and when therefore the supply of nitrates to the plant will be greater under the same conditions of soil than in the case of wheat. This would be a very interesting subject for investigation, in the field and in the laboratory, tracing the nitrogen at various periods in the soil, in the plant, and in the drainage waters.

The following table (XIII.) gives estimates of the yield of various crops on some Manitoba prairie soils:

TABLE XIII.

*Estimates of the yield of various Crops in Manitoba.*Summary of Statistical Returns—seven years, 1876-1882.  
Quantities in bushels per acre.

	1876	1877	1878	1879	1880	1881	1882	GEN'L AVER.
Wheat,	32	27	26	27	29	30	32	29
Barley,	42	41	36	38	41	40	37	39
Oats,	51	60	60	58	58	59	51	57
Rye,	—	30	30	40	40	35	—	35
Peas,	32	32	34	32	38	38	—	34
Potatoes,	229	304	308	302	318	320	278	294

The above estimates are founded on the reports of numerous farmers, and it is seen that the average yield of wheat for seven years (1876-1882) is assumed to be twenty-nine bushels. This is, however, doubtless too high, even for exclusively virgin prairie soils, under the condition of cultivation incident to new settlement; and the result is probably accounted for by the fact that the records come chiefly from the more intelligent and better farmers. From returns since supplied to me from the Department of Agriculture at Ottawa, the average produce of wheat in Manitoba was, in 1880, 20.1 bushels, and in 1882, 24.0 bushels, instead of 29 and 32 bushels as above; whilst the average produce in 1883 is estimated at 21.8 bushels.

In connection with this subject of the average yield of wheat of different countries, it will be of interest to contrast the condition of soils of very different history, as to their percentage of nitrogen, and, so far as we are able, of carbon also.

Table XIV. (see next page) shows the characters in these respects of exhausted, arable soils, of newly laid down pasture, and of old pasture soils, at Rothamsted; of some other old arable soils; of some Illinois and Manitoba prairie soils; and lastly, of some very rich Russian soils.

From these results there can be no doubt that a characteristic of a rich virgin soil, or of a permanent pasture surface-soil, is a relatively high percentage of nitrogen and of carbon, and a high relation of carbon to nitrogen. On the other hand, a soil that has long been under arable culture is much poorer in these respects; whilst an arable soil under conditions of known agricultural exhaustion shows a very low percentage of nitrogen and of carbon, and a low relation of carbon to nitrogen.

Finally, it has been maintained by some that a soil is a laboratory, and not a mine. But not only the facts ascertained in our own and in other investigations, but the history of agriculture throughout the world, so far as we know it, clearly show that a fertile soil is one which has accumulated within it the residue of ages of previous vegetation, and that it becomes infertile as this residue is exhausted; and enormous as are the accumulations in the prairie lands of the American continent, it is still desirable to postpone, rather than to accelerate, the time of their exhaustion.

TABLE XIV.  
Nitrogen and Carbon in various soils.

	Date of Soil Sampling.	(1) In Dry Sifted Soil.			Authority.
		Nitrogen.	Carbon.	Carbon to 1 Nitrogen.	
ROTHAMSTED ARABLE AND GRASS SOILS.					
Roots, 1843-'52; Barley, 1853-'5; } Roots, 1856-'69; Mineral Manures. } Wheat, 1843-'4, and each year since; } Mineral Manures..... } Barley, 1852, and each year since; } Mineral Manures..... } Arable laid down to grass (ten } acres), Spring, 1879..... } Arable laid down to grass (Barn- } field), Spring, 1874..... } Arable laid down to grass (Apple- } tree field), Spring, 1863..... } Arable laid down to grass (Dr. Gil- } bert's meadow), Spring, 1858..... } Arable laid down to grass (High- } field), Spring (9), 1838..... } Very old grass land (The Park)..... }	April, 1870 .....	0.0934	.....	.....	Rothamsted.
	October, 1865 .....	0.1119	1.039	9.3	"
	October, 1881 ..	0.1012	1.079	10.7	"
	March, 1868 .....	0.1202	.....	.....	"
	March, 1882 .....	0.1124	1.154	10.3	"
	February, 1882..	0.1235	.....	.....	"
	February, 1882..	0.1509	.....	.....	"
	November, 1881.	0.1740	.....	.....	"
	January, 1879 ...	0.2057	2.412	11.7	"
	September, 1878.	0.1943	2.403	12.4	"
	Feb. & Mch., 1876	0.2466	3.377	13.7	"
VARIOUS ARABLE SOILS IN GREAT BRITAIN.					
Mr. Prout's Farm; Broadfield— } surface..... } Mr. Prout's Farm; Blackacre— } surface..... } Mr. Prout's Farm; Whitemoor— } surface..... }	.....	0.170	.....	.....	Voelcker.
	.....	0.107	.....	.....	"
	.....	0.171	.....	.....	"
Wheat Soil—Midlothian.....	.....	0.22	.....	.....	Anderson.
" Eastlothian.....	.....	0.13	.....	.....	"
" Perthshire.....	.....	0.21	.....	.....	"
" Berwickshire.....	.....	0.14	.....	.....	"
Red Sandstone Soil—England.....	.....	0.18	.....	.....	Voelcker.
UNITED STATES AND CANADIAN PRAIRIE SOILS.					
Illinois, U. S., No. 1.....	.....	0.30	.....	.....	Voelcker.
" " No. 2.....	.....	0.26	.....	.....	"
" " No. 3.....	.....	0.33	.....	.....	"
" " No. 4.....	.....	0.34	.....	.....	"
Portage la Prairie, Manitoba—sur- } face..... } Saskatchewan district, N. W. Terri- } tory—surface..... } Forty miles from Fort Ellis, N. W. } Territory—surface..... }	.....	0.247	.....	.....	Rothamsted.
	.....	0.303	.....	.....	"
	.....	0.250	.....	.....	"
Niverville, Manitoba—1st 12 inches.	.....	0.261	3.42	13.1	Rothamsted.
Brandon, " ".....	.....	0.187	2.66	14.2	"
Selkirk, " ".....	.....	0.618	7.58	12.3	"
Winnipeg, " ".....	.....	0.428	5.21	12.2	"
RUSSIAN SOILS.					
No. 1—12 inches.....	.....	0.607	.....	.....	C. Schmidt.
No. 2—8 ".....	.....	0.467	.....	.....	"
No. 3—5 ".....	.....	0.188	.....	.....	"
No. 4—6 ".....	.....	0.130	.....	.....	"
No. 5—11 ".....	.....	0.305	.....	.....	"
No. 6—17 ".....	.....	0.281	.....	.....	"
No. 7—9 ".....	.....	0.409	.....	.....	"

(1) Calculated on soil dried at 100 C.