LECTURE ON AGRICULTURAL INVESTIGATIONS

GILBERT

1884

With the compliments of HOUGHTON FARM.

ON

AGRICULTURAL INVESTIGATION;

BEING

A LECTURE DELIVERED OCTOBER 27, 1884,

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	4¼	29
Oats (various manures)	10[1]	¾	6
Beans (various manures)	32[2]	1¼	10
Beans (various manures)	27[3]	1	5
Beans alternated with wheat	28[4]	1	10
Clover (various manures)	30[5]	3	18
Various Leguminous Plants	7	3	17
Turnips (various manures)	28[6]	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	2½	12
Permanent Grass (various manures)	29	7	22

(1) Including 1 year fallow.
(2) " 1 " wheat and 5 years fallow.
(3) " 4 years fallow.
(4) " 2 " "
(5) Clover, 12 times sown, 8 yielding crops, but 4 of them very small, 1 year wheat, 5 years barley, 12 years fallow.
(6) 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 evergreen 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.

	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.	
Plot Nos.	2	3	5	17	18	16	10a	10b
Harvests.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.
1844	20½	15					15½	
1845	32	23¼					31⅞	
1846	27¼	18					27⅜	17⅝
1847	29⅞	16⅞					25¾	25¾
1848	25⅝	14¾					19¼	25½
1849	31	19¼					32⅝	32⅜
1850	28½	15⅞					27	18
1851	29⅝	15⅞					28⅞	28⅝
8 yrs. '44-'51	28	17⅜	29	30¼	28⅞	30¾	26	24⅜
1852	27⅝	13⅞	16⅞	24⅞	14⅜	28½	21⅞	22⅛
1853	19⅛	5⅞	10⅛	8⅝	19¼	25⅛	10	15½
1854	41⅛	21⅛	24¼	44¼	23⅞	49⅞	34⅜	39¼
1855	34⅝	17	18¼	18	33¼	32⅞	20	28⅛
1856	36¼	14½	19½	31	17⅞	37⅞	24¼	27¾
1857	41¼	20	23¾	26¼	40½	49⅜	29⅛	34½
1858	38¾	18	18⅞	33½	21¾	41⅞	22⅞	27¾
1859	36¼	18⅜	20⅝	20½	32⅝	34⅝	19	25½
1860	32¼	12⅞	15⅞	25¼	15¾	32⅝	15⅛	18⅝
1861	34⅞	11⅜	15½	18¾	32⅞	37	12⅞	16
1862	38⅜	16	17¾	27¾	18½	36¼	23½	24⅞
1863	44	17¼	19⅝	21¼	46¼	55⅞	39⅛	43⅝
1864	40	16½	16⅞	36⅛	17⅝	51⅛	32⅛	36¼
1865	37⅛	13⅜	14¼	17	31⅜	32⅜	25¼	30½
1866	32⅝	12⅛	13¼	26½	12⅝	17⅜	26¼	28½
1867	27½	8⅞	9¼	10¾	23⅝	14⅝	18⅛	19⅜
1868	41¾	16⅝	17⅝	37⅜	18⅝	22¾	24¾	27¾
1869	38¼	14¼	15¾	16⅛	22⅞	16⅛	20¼	19⅛
1870	36½	15	18⅞	34⅜	19	18¼	21¾	23¼
1871	39	9⅜	11⅞	16	28⅜	13½	10⅛	10
1872	31⅜	10¾	12¾	25⅛	13	13⅛	18	18¾
1873	26¾	11¾	12¾	11¾	20⅜	12¾	19⅝	20⅝
1874	39¼	11½	13	33¼	14	11⅞	25¼	27¼
1875	28⅞	8⅝	9¼	11⅝	25⅝	10⅛	12¾	14⅝
1876	23⅞	8⅛	10½	26½	10⅜	11	12⅛	14½
1877	24⅛	8⅞	11⅝	10	12⅝	9⅞	17¼	18¼
1878	28¼	12⅜	14¾	29	15¼	13⅝	27⅜	29⅞
1879	16	4¾	5⅝	3⅛	20⅜	4⅞	4	4⅝
1880	38⅜	11½	17¾	32¾	15	14⅝	10⅝	13½
1881	30¼	13¾	12¾	13¼	32	13½	18¼	19¾
1882	32¾	11	12½	31	15⅝	10¾	23¾	26⅛
1883	35¼	13⅞	15¾	15⅜	38¼	15⅞	17½	18⅜
AVERAGES.								
4 yrs. '52-'55	30⅝	14½	17⅜	16¼	30⅜	34	21½	26¼
4 yrs. '56-'59	38	17¾	20¾	21⅝	34⅜	41	23⅞	28⅞
4 yrs. '60-'63	37⅜	14⅜	17¼	18½	33	(1) 42⅝	22½	25¾
4 yrs. '64-'67	34¼	12¾	13⅜	14½	29⅜	(2) 21½	25½	28⅝
4 yrs. '68-'71	38⅞	13¾	16	17⅜	30¾	17⅝	19¼	20
4 yrs. '72-'75	31½	10⅝	12	12⅝	26¼	12	18⅞	20¼
4 yrs. '76-'79	23	8½	10⅝	9¾	22⅛	9⅞	15¼	16⅞
4 yrs. '80-'83	34⅛	12½	14¾	14¾	33½	13¾	17½	19½
8 yrs. '52-'59	34⅜	16⅛	19	18⅞	32⅜	37½	22¾	27½
8 yrs. '60-'67	35¾	13½	15¼	16½	31¼	(3) 42⅝	24	27¼
8 yrs. '68-'75	35¼	12¼	14	15	28½	(4) 16⅝	19	20⅛
8 yrs. '76-'83	28⅝	10½	12⅝	12¼	27¾	11¾	16⅜	18⅛
16 yrs. '52-'67	35⅛	14⅞	17⅛	17¾	31¾	(5) 39⅛	23⅜	27⅜
16 yrs. '68-'83	31⅞	11⅜	13⅜	13⅝	28⅛	(6) 14⅝	17¾	19⅛
32 yrs. '52-'83	33½	13⅛	15¼	15⅝	30	24¾	20½	23¼
40 yrs. '44-'83	32⅜	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 23¼ bushels in 1845, and the lowest was 4¾ bushels in 1879. Other yields have been 21⅛ bushels in 1854, 20 in 1857, only 5⅞ 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 14½, 17¾, 14⅜, 12¾, 13¾, 10⅝, 8½, and 12½ bushels; over the eight-year periods, 16⅛, 13½, 12¼, and 10½; over the sixteen-year periods, 14⅞ and 11⅜; over the thirty-two years, 13⅛, 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, 41¾ in 1868, 41¼ in 1857, and 41⅛ in 1854. The lowest yields were 16 bushels in 1879, 19⅛ in 1853, 20½ in 1844, 23⅞ in 1876, and 24⅛ in 1877.

The average produce per acre per annum over each of the five eight-year periods was, 28, 34⅜, 35¾, 35¼, and 28⅝ 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 BUSHELS.

	Superphosphate, and Sulphates Potash, Soda, and Magnesia.					
	Alone.	& Amm.-salts =43 lbs. Nitrogen.	& Amm.-salts =86 lbs. Nitrogen.	& Amm.-salts =129 lbs. Nitrogen.	& Sodium Nitrate =86 lbs. Nitrogen.	Sodium Nitrate alone. =86 lbs. Nitrogen.
Plots.	5	6	7	8	9a	9b
Harvests.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.
1852	16⅞	20⅞	26¾	27½	25½	24½
1853	10⅛	18⅛	23⅝	23½	11¼	10½
1854	24¼	34⅛	45½	48⅝	38¾	38⅞
1855	18¼	28	33	31½	29⅝	25⅜
1856	19½	27¾	36⅞	39⅛	32⅜	26
1857	23¾	35⅜	44⅞	48⅜	43¾	36¼
1858	18⅞	28⅞	39⅛	41⅞	37⅝	23½
1859	20⅝	29⅞	34⅝	34½	30	24⅝
1860	15⅞	22	27¾	31¼	32⅝	19⅝
1861	15½	27⅝	35	35⅛	33¾	13¾
1862	17¾	28¼	35⅞	39½	43½	25⅞
1863	19⅝	39⅝	53⅝	55¾	55⅝	41½
1864	16⅞	31⅛	45¾	49⅞	51⅛	33¼
1865	14¼	25	40¼	43⅝	44⅛	29⅝
1866	13¼	20½	29⅞	32⅛	32½	30¾
1867	9¼	15¾	22⅛	30½	29⅛	22⅛
1868	17⅝	28⅜	39⅞	46½	47⅞	27¼
1869	15¾	21⅝	28⅜	34¾	39	24⅛
1870	18⅞	30½	40½	45¼	45½	26½
1871	11⅞	17	22¼	27¾	34½	17⅝
1872	12¾	20½	29¾	35⅝	40¼	23⅜
1873	12¾	15⅞	22	27½	35⅞	21⅞
1874	13	25⅞	39½	40½	38¼	21½
1875	9¼	16⅜	25⅞	30	30½	16½
1876	10½	15¾	23½	29⅝	33⅜	13
1877	11⅝	14⅝	19⅞	24¾	40⅛	27¾
1878	14¾	22¾	31¼	38⅛	37¼	23⅜
1879	5⅝	10½	16¼	20⅝	22	4⅝
1880	17¾	27	34½	35⅜	34⅛	10½
1881	12¾	21¾	26⅝	30¾	35½	22¾
1882	12½	23⅛	35¾	37	31⅞	24⅜
1883	15¾	27⅝	36⅛	41⅞	43⅜	19⅛
AVERAGES.						
4 ys. '52-55	17⅜	25¼	32¼	32¾	26¼	24¾
4 ys. '56-59	20¾	30½	38⅞	41	36	27⅝
4 ys. '60-63	17¼	29⅜	38	40⅜	41⅜	25¼
4 ys. '64-67	13⅜	23⅛	34½	39	39¼	29
4 ys. '68-71	16	24⅜	32¾	38½	41¾	23⅞
4 ys. '72-75	12	19⅝	29¼	33⅜	36⅜	20⅞
4 ys. '76-79	10⅝	15⅞	22¾	28¼	33¼	17¼
4 ys. '80-83	14¾	24⅞	33¼	36¼	36¼	19¼
8 ys. '52-59	19	27⅞	35½	36⅞	31⅛	26¼
8 ys. '60-67	15¼	26¼	36¼	39¾	40¼	27⅛
8 ys. '68-75	14	22	31	36	39	22⅜
8 ys. '76-83	12⅝	20⅜	28	32¼	34¾	18¼
16 ys. '52-67	17⅛	27	35⅞	38¼	35¾	26⅝
16 ys. '68-83	13⅜	21¼	29½	34⅛	36⅞	20¼
32 ys. '52-83	15¼	24⅛	32¾	36¼	36¼	23½
Excess of average crop over Plot 5 in bush.	—	8⅞	17½	21	21	8¼

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 2⅛ 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 8⅞ bushels, the second 43 lbs. (plot 7) an increase of 8⅝, and the third 43 lbs. only 3½ 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.	
Wheat 20 years—1852,'71.	ACTUAL LBS.	LBS. GAIN.
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 chlorophyl 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 chlorophyl 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 chlorophyl formation has a close connection with the amount of nitrogen assimilated; but that the carbon assimilation is not in proportion to the chlorophyl 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 chlorophyl 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 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 39½ bushels. The first three years during which no manure was applied, the average yield was only 21½ bushels, a decrease of nearly one-half, followed in the succeeding periods of four years each by average yields of 17⅝, 12, 9⅞, and 13¾ bushels; against, for the corresponding periods on plot 3, continuously without manure, 8½, 13¾, 10⅝, and 12½ bushels. Or, taking the average of the nineteen years of yield without manure on plot 16, we have 14⅝ bushels, against, over the same years, 13⅛ bushels, on plot 5, with mineral manures only, since 1852, and 11⅜ 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.						
	Mixed Mineral Manure Alone.	Alone, 1852 and since. Previo'sly Min. Man. 1844. Am.-Salts 1845–51.	Alone, 1852 and since. Prev'sly 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 Superphosph'te 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.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.
8 yrs. '44,'51	29	26	24⅜	28½	28⅛	27⅝	27¼	29¼
1852	16⅞	21⅞	22⅛	23¼	24⅜	24	24¾	26¾
1853	10⅛	10	15½	18⅛	22⅞	23	22⅜	23⅝
1854	24¼	34⅜	39¼	43⅞	45⅝	44½	44¾	45½
1855	18¼	20	28⅓	21¾	31¾	30¾	31⅝	33
1856	19½	24¼	27¾	31¼	33⅜	31⅝	34⅝	36⅞
1857	23¾	29⅛	34½	39⅛	43¾	43⅛	43⅜	44⅞
1858	18⅞	22⅞	27¾	32	37⅝	37¼	38⅛	39⅛
1859	20⅝	19	25½	27⅜	34¾	34½	34½	34⅝
1860	15⅞	15⅛	18⅝	22⅜	27⅜	26⅝	27¼	27¾
1861	15½	12⅞	16	24⅜	32⅞	34⅛	33½	35
1862	17¾	23½	24⅞	26⅞	33¾	32⅜	31¼	35⅞
1863	19⅝	39⅛	43⅝	45¾	54	53¼	54	53⅝
1864	16⅞	32⅛	36¼	36½	44⅝	43¼	41½	45¾
1865	14¼	25¼	30½	27⅜	34⅝	37⅛	36⅝	40¼
1866	13¼	26¼	28½	28	28¼	24¾	28	29⅞
1867	9¼	18⅛	19⅜	22⅛	24½	23⅞	22¾	22⅛
1868	17⅝	24¾	27¾	33½	39⅞	39¼	41¾	39⅞
1869	15¾	20¼	19⅛	22¼	27¼	27¼	27¾	28⅜
1870	18⅞	21¾	23¼	25¼	35¼	37	35¾	40½
1871	11⅞	10⅛	10	11	21⅛	30⅛	24¼	22¼
1872	12¾	18	18¾	27¼	29¼	29⅞	30⅜	29¾
1873	12¾	19⅝	20⅝	19¼	22⅞	23½	24⅛	22
1874	13	25¼	27¼	32⅞	39½	37⅛	36⅝	39½
1875	9¼	12¾	14⅝	18	25¼	27⅛	26¼	25⅞
1876	10½	12⅛	14½	14⅜	19⅛	25⅛	22⅛	23½
1877	11⅝	17¼	18¼	17⅞	17¾	18¼	18½	19⅞
1878	14¾	27⅜	29⅞	29⅝	29¼	29½	32⅛	31¼
1879	5⅝	4	4⅝	11⅛	14	16	16¼	16¼
1880	17¾	10⅝	13½	25¾	29⅜	33	31	34½
1881	12¾	18¼	19¾	21½	23¾	28¼	27⅜	26⅝
1882	12½	23¾	26⅛	30⅜	34⅝	32⅛	34¾	35¾
1883	15¾	17½	18⅜	26⅜	30¾	34⅛	33⅜	36⅛

AVERAGES.

4 yrs. '52,'55	17⅝	21½	26¼	26¾	31¼	30⅝	30⅞	32¼
4 yrs. '56,'59	20¾	23⅞	28⅞	32½	37½	36⅝	37⅝	38⅞
4 yrs. '60,'63	17¼	22½	25¾	29⅞	37	36⅝	36½	38
4 yrs. '64,'67	13⅜	25½	25⅝	28½	33	32¼	32¼	34½
4 yrs. '68,'71	16	19¼	20	23	30⅞	33⅜	32⅜	33¾
4 yrs. '72,'75	12	18⅞	20¼	24⅜	29¼	29⅜	29⅜	29¼
4 yrs. '76,'79	10⅝	15¼	16⅞	18¼	20	22¼	22¼	22¾
4 yrs. '80,'83	14¾	17½	19½	26	29⅝	31⅞	31⅝	33¼
8 yrs. '52,'59	19	22¾	27½	29⅝	34¼	33⅝	34¼	35½
8 yrs. '60,'67	15¼	24	27¼	29⅛	35	34⅜	34⅜	36¼
8 yrs. '68,'75	14	19	20⅛	23⅝	30	31⅜	30⅞	31
8 yrs. '76,'83	12⅝	16⅜	18⅛	22⅛	24⅞	27	27	28
16 yrs. '52,'67	17⅛	23⅜	27⅜	29⅜	34⅝	34	34⅜	35⅞
16 yrs. '68,'83	13⅜	17¾	19⅛	22⅞	27½	29¼	28⅞	29½
32 yrs. '52,'83	15¼	20½	23¼	26⅛	31	31⅝	31⅝	32¾
	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 17⅛ bushels per acre, during the second sixteen years 13⅜ bushels, and during the whole period of thirty-two years 15¼ bushels.

Plot 10a, treated with ammonium-salts only, gave, during the first sixteen years, an average yearly yield of 23⅜ bushels per acre, during the second sixteen years 17¾ bushels, and during the thirty-two years an average of 20½ 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 27⅜ bushels per acre, against 23⅜ bushels on 10a; during the second period of sixteen years 19⅛ bushels, against 17¾ on 10a; and during the thirty-two years, an average yearly yield of 23¼ bushels, against only 20½ 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 29⅜ bushels per acre, during the second sixteen years 22⅞ bushels, and during the thirty-two years 26⅛ 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 34⅝ bushels per acre, the second sixteen years of 27½ 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 29¼, and over the thirty-two years 31⅝ 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 34⅜ bushels, over the second sixteen years 28⅞ bushels, and over the thirty-two years 31⅝ 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 35⅞ bushels per acre, during the second sixteen years of 29½ bushels, and during the whole thirty-two years of 32¾ 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 PRODUCE.	GRAIN	TOTAL PRODUCE.	GRAIN	TOTAL PRODUCE.	GRAIN	TOTAL PRODUCE.	GRAIN
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	13⅛
2	Farm-yard Manure	44	16	28	33½
5	Mixed Mineral Manure, alone	19⅝	5⅝	14	15¼
6	Mixed Min. Man. and 200 lbs. Amm.-Salts = 43 lbs. Nit.	39⅝	10½	29⅛	24⅛
7	Mixed Min. Man. and 400 lbs. Amm.-Salts = 86 lbs. Nit.	53⅝	16¼	37⅜	32¾
9	Mixed Min. Man. and 550 lbs. Nitra. Soda = 86 lbs. Nit.	55⅝	22	33⅝	36¼
8	Mixed Min. Man. and 600 lbs. Amm. Salts = 129 lbs. Nit.	55¾	20⅝	35⅛	36¼

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 nitrogeneous 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. 8 years—1856–'63. Broadbalk Field.	Rothamsted. 8 years—1856–'63. Hoos Field.	Rothamsted. 32 years—1852–'83. Broadbalk Field.	Woburn, Beds, 7 years. 1877–'83.	Holkham, Norfolk, 3 years. 1852–'54.	Rodmersham, Kent 4 years. 1856–'59.
Unmanured	16	15	13⅛	15⅞	18	25⅝
Mixed Mineral Manure, alone	19	16⅛	15¼	16⅞	19⅛	28½
Amm.-Salts, alone=86 lbs. N.	23¼	26⅛	20⅞	23⅝ 1)	27¼	31½
Mixed Mineral Manure, and Ammonium-Salts=86 lbs.N.	38½	37⅜	32¾	37⅝	32⅝	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 (43½ and 45¾ bushels); whereas, the portion on which mineral manures alone succeeded ammonium-salts and large crops, yielded very small crops — 13¼ and 17¼ bushels, respectively, against 14⅞ and 17¼ 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	43⅜	
1878	27	
1879	31¼	
1880	28⅜	
1881	43⅝	
1882	(1) 13¼	(2) 43½
1883	(2) 45¾	(1) 17¼

(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 28¼, but that for the second sixteen years only 25¾. 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 2¼ bush's per acre for seed.	Imports less Exports.	Total.	From Home Produce.	From Imports.	Total.
	Acres.	Bushl.	Quarters.	Quarters.	Quarters.	Quarters.	Bush.	Bush.	Bush.
1852-3	4.058.731	22⅞	11.574.982	10.433.464	5.902.000	16.335.464	3.03	1.71	4.74
1853-4	4.013.963	20⅞	10.466.473	9.337.546	6.092.000	15.429.546	2.70	1.76	4.46
1854-5	4.036.969	34¾	17.563.140	16.427.742	2.983.000	19.410.742	4.73	0.85	5.58
1855-6	4.076.447	27⅜	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	33⅛	17.321.221	16.143.915	5.795.687	21.939.602	4.56	1.63	6.19
1858-9	4.131.822	31½	16.309.949	15.147.874	4.555.670	19.703.544	4.24	1.28	5.52
1859-60	4.019.725	26⅛	13.135.124	12.004.575	4.516.332	16.520.907	3.34	1.25	4.59
1860-1	3.992.657	22⅛	11.078.948	9.956.012	10.023.968	19.979.980	2.75	2.77	5.52
1861-2	3.898.177	25¼	12.271.546	11.175.183	9.099.455	20.274.638	3.06	2.49	5.55
1862-3	3.823.947	29¼	13.957.554	12.882.069	9.205.086	22.087.155	3.51	2.51	6.02
1863-4	3.698.629	38¾	17.922.048	16.881.807	6.991.270	23.873.077	4.57	1.89	6.46
1864-5	3.685.493	35¼	16.216.328	15.179.783	5.500.705	20.680.488	4.08	1.48	5.56
1865-6	3.646.691	30⅝	13.975.936	12.950.305	7.313.026	20.263.331	3.47	1.95	5.42
1866-7	3.649.584	25⅛	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	22½	10.290.417	9.261.375	11.301.316	20.562.691	2.29	2.80	5.09
1874-5	3.821.655	29¼	13.972.926	12.898.085	11.705.255	24.603.340	3.16	2.87	6.03
1875-6	3.503.709	22⅞	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	26½	10.970.533	10.039.073	14.408.628	24.447.701	2.38	3.42	5.80
1878-9	3.372.590	30	12.647.213	11.698.672	14.145.649	25.844.321	2.75	3.32	6.07
1879-80	3.047.752	15½	5.905.020	5.047.840	16.409.933	21.457.773	1.17	3.82	4.99
1880-1	3.057.784	24½	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	25⅝	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	26½	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	29½	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	28⅞	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	28¾	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	24⅝	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	24¼	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	25½	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	28½	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	26⅝	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	24⅞	9.636.682	8.754.751	15.781.483	24.536.234	2.03	3.64	5.67
16 yrs.'52-'68	3.922.586	28¼	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	25¾	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.

	1875	1876	1877	1878	1879	1880	Gl.Av.
WHEAT—BUSHELS.							
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.							
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. Nitrogen.	Carbon.	Carbon to 1 Nitrogen.	Authority.
ROTHAMSTED ARABLE AND GRASS SOILS.					
		Per cent.	Per cent.	Per cent.	
Roots, 1843-'52; Barley, 1853-'5; Roots, 1856-'69; Mineral Manures.	April, 1870	0.0934	....	....	Rothamsted.
Wheat, 1843-'4, and each year since; Mineral Manures......	October, 1865....	0.1119	1.039	9.3	"
	October, 1881 ..	0.1012	1.079	10.7	"
Barley, 1852, and each year since; Mineral Manures................	March, 1868	0.1202	....	....	"
	March, 1882	0.1124	1.154	10.3	"
Arable laid down to grass (ten acres), Spring, 1879..............	February, 1882..	0.1235	....	....	"
Arable laid down to grass (Barnfield), Spring, 1874................	February, 1882..	0.1509	....	....	"
Arable laid down to grass (Appletree field), Spring, 1863...........	November, 1881 .	0.1740	....	....	
Arable laid down to grass (Dr. Gilbert's meadow), Spring, 1858	January, 1879 ...	0.2057	2.412	11.7	"
Arable laid down to grass (Highfield), Spring (?), 1838.............	September, 1878.	0.1943	2.403	12.4	"
Very old grass land (The Park)......	Feb. & Mch., 1876	0.2466	3.377	13.7	"
VARIOUS ARABLE SOILS IN GREAT BRITAIN.					
Mr. Prout's Farm; Broadfield—surface..........................	......	0.170	....	....	Voelcker.
Mr. Prout's Farm; Blackacre—surface....	......	0.107	....	....	"
Mr. Prout's Farm; Whitemoor—surface...........................	......	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—surface..........................	......	0.247	....	....	Rothamsted.
Saskatchewan district, N. W. Territory—surface..................	......	0.303	....	....	"
Forty miles from Fort Ellis, N. W. Territory—surface	......	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.