445

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN NO. 106.

A. C. TRUE, Director.

RESULTS OF INVESTIGATIONS ON THE ROTHAMSTED SOILS,

BEING THE LECTURES DELIVERED UNDER
THE PROVISIONS OF

THE LAWES AGRICULTURAL TRUST,

BY

BERNARD DYER, D. Sc. (Lond.), F. I. C., F. C. S., F. L. S.

Before the Association of American Agricultural Colleges and Experiment Stations at New Haven and Middletown, Conn., in November, 1900.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1902.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN NO. 106.

A. C. TRUE, Director.

RESULTS OF INVESTIGATIONS ON THE ROTHAMSTED SOILS,

BEING THE LECTURES DELIVERED UNDER THE PROVISIONS OF

THE LAWES AGRICULTURAL TRUST,

BY

BERNARD DYER, D. Sc. (Lond.), F. I. C., F. C. S., F. L. S.

Before the Association of American Agricultural Colleges and Experiment Stations at New Haven and Middletown, Conn., in November, 1900.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1902.

OFFICE OF EXPERIMENT STATIONS.

A. C. TRUE, Ph. D.—*Director.*

E. W. ALLEN, Ph. D.—*Assistant Director.*

W. H. BEAL—*Editor of Experiment Station Work and Miscellaneous Bulletins.*

EDITORIAL DEPARTMENTS.

E. W. ALLEN, Ph. D., and H. W. LAWSON—*Chemistry, Dairy Farming, and Dairying.*

W. H. BEAL—*Meteorology, Fertilizers and Soils (including methods of analysis) and Agricultural Engineering.*

WALTER H. EVANS, Ph. D.—*Botany and Diseases of Plants.*

C. F. LANGWORTHY, Ph. D.—*Foods and Animal Production.*

J. I. SCHULTE—*Field Crops.*

E. V. WILCOX, Ph. D.—*Entomology and Veterinary Science.*

C. B. SMITH—*Horticulture.*

D. J. CROSBY—*Agricultural Institutions.*

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., January 8, 1902.

Sir: I have the honor to transmit herewith for publication as Bulletin No. 106 of this Office a series of lectures on soil investigations at Rothamsted, England, delivered under the provisions of the Lawes Agricultural Trust, by Bernard Dyer, D. Sc., before the convention of the Association of American Agricultural Colleges and Experiment Stations at New Haven and Middletown, Conn., November, 1901. These lectures are recommended for publication in full, not only on account of their intrinsic value, but in conformity with the wish of the late Sir John Lawes, frequently expressed during the later years of his life, "that all statistical matter relating to observations and experiments on the Rothamsted soils should be brought together (as he expressed it) 'between one pair of covers.'" These observations and experiments have extended over a number of years and have been partly published elsewhere, but by far the greater portion of the matter contained in these lectures, including the results of the author's recent exhaustive studies on the phosphoric acid and potash contents of Rothamsted soils, is new. It is fitting that ackowledgment should here be made of the munificence and splendid devotion to agricultural science which prompted Sir John Lawes not only to found and maintain for many years, but to endow in perpetuity, the great experiment station at Rothamsted, and of the kindly interest in American agriculture which led him at the same time to provide for a series of biennial lectures in the United States on the work of that station, in order, as he stated, that Americans might feel that they had a share in any of the benefits which might arise from the Rothamsted endowment.

Since these lectures were prepared for publication, Sir J. Henry Gilbert, who for over fifty-five years was the associate of Sir John Lawes at Rothamsted, has also passed away from the scene of his lifelong labors. He died on December 23, 1901, at the age of nearly 85 years.

The lectures transmitted herewith are the fourth of the courses so provided for and the third to be published as bulletins of this Department. The first course, delivered at Washington, D. C., August, 1891, by Robert Warington, F. R. S., gave a brief account of the Rothamsted Experiment Station, but dealt mainly with the work of that station on the changes (nitrification and denitrification) which nitrogenous compounds undergo in the soil, and on drainage and well waters. These lectures were published in an edition of 5,000 copies as Bulletin No. 8 of this Office, but the bulletin is now out of print. The second, which was a carefully prepared review of the field and feeding experiments at Rothamsted during half a century, by Sir Joseph Henry Gilbert, M. A., LL. D., F. R. S., was published in an edition of 6,000 copies as Bulletin No. 22 of this Office, and is also out of print.

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

RESULTS OF INVESTIGATIONS ON THE ROTHAMSTED SOILS.

INTRODUCTION.

It is my privilege to appear before you as the delegate of the Lawes Agricultural Trust Committee, to offer once again, for your acceptance, a digest of the results of some of the work carried out at Rothamsted. When the late Sir John Bennett Lawes permanently endowed and dedicated to the public his famous experimental station, he recognized, as you will recollect, the interest which you in America had long shown in Rothamsted, by making provision in the trust deeds for the periodical delivery here of what have now come to be known as the Rothamsted lectures.

The first to fulfill the mission was Professor Warington, in 1891; the next was Sir John's veteran colleague, Sir J. Henry Gilbert, who visited you in 1893; while the last, in 1897, was Professor Armstrong, who acts on the Lawes Agricultural Trust Committee as the representative of the Chemical Society.

This, therefore, is the fourth occasion on which official greeting passes personally and by word of mouth from the time-honored institution in England to the representatives of the many younger but already vigorous and flourishing kindred institutions which have grown up on your side.

My visit to you occurs at a time which is one of mourning for all who care for Rothamsted and its work. Sir John Lawes passed away from us on the last day of August this year, at what would usually be called the ripe old age of nearly 86. But the use of this conventional phrase would not be applicable to his case. Ripe his life was in one sense, in so far as ripeness is an emblem of maturity, of service, of usefulness, of the potentiality to feed, enrich, and adorn. All this his life did for the mental life of all who intelligently study agriculture; and much also has it done directly and indirectly, in a physical sense, to mitigate the troubles and advance the well-being of thousands of his fellow-agriculturists at home and abroad. But in the sense of being ripe for the harvest, his life was not ripe. Though full of years he was of such a fine and vigorous constitution, and still mentally so young and fresh, that his friends confidently foretold for him many years yet of active work. There was no fading into the mental repose that gradually creeps into the life that is lived. An unfortunate seizure of a zymotic type, purely adventitious and indiscriminate in its choice of victims between youth and age, terminated his labors at a few days' notice.

The life and career of Sir John Lawes up to ten years since were ably sketched to you by Professor Warington at the opening of the first series of these lectures,[1] and I will therefore now not do more than thus briefly record the temporal death of one who will live perennially in scientific history as one of the most remarkable figures of the century that is just drawing to its close. I would like, however, to add that during the last three years he had looked forward with much interest to the delivery to you of the lectures which, at his own request, have been intrusted to my unworthy hands, that he has often personally discussed with me their scope and material, and that, within a very few days of his death, his last act of work was to discuss with Sir Henry Gilbert the selection of some of the matter which he and his colleague desired to be brought before you on this occasion.

You are well aware of the scope and nature of the long-continued and multifarious work carried on at Rothamsted, not merely from the bulletins or "memoranda" which are annually transmitted to many of you individually, but also through the comprehensive lectures in which Sir Henry Gilbert, on the occasion of his last visit to your country, summed up a large part of the work of no less than fifty years of research.[2] Among the matters which he brought to your notice was much of the chemical work which had been done in the examination from time to time of certain of the experimental soils, some of which had, indeed, been brought to your notice by my earlier predecessor, Professor Warington. With the exception, however, of some special work of my own on the barley soils, the latest systematic series of analyses which had then been made was that of the samples of the Broadbalk wheat field collected in 1881. During the year of Sir Henry Gilbert's visit to you, however, viz, in 1893, a complete set of new samples was taken from this field on the completion of the fiftieth consecutive wheat crop; and these samples have since been submitted to examination in various ways in the Rothamsted laboratory, and also with regard to certain special points, by the kind permission of the committee, in my own laboratory. The result has naturally been to add much to the already valuable knowledge arrived at by the analyses of the earlier samples, many of which early samples, it may be added, have been reexamined since by myself in the light of later work in certain directions not contemplated when the samples were originally taken. We have thus, with the old results and the new, a large mass of information relating to the chemistry of the wheat soils, which it has been the desire of both Sir John Lawes and Sir Henry Gilbert to have presented now in a

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 8.

[2] U. S. Dept. Agr., Office of Experiment Stations Bul. 22.

collected and comprehensive form, not merely that its general outcome may be seen, but also that the detailed figures of the great number of determinations (of which a large proportion are new and hitherto unpublished, while others are scattered over the pages of various separate memoirs and lectures) may be embodied and preserved in a collected form for the future reference of those who may from time to time wish to restudy the results. It has, at the same time, been their desire to collate with these, in certain directions, the results obtained from the examination of other of the experimental soils. The task of completing and presenting to you this collation has been intrusted to my hands. The wealth of material has made anything like an adequate discharge of the task, within the necessarily confined limits of these lectures, a matter of impossibility, for the work might more easily be expanded to a series of volumes. The material itself, however, will be transcribed for the leisurely detailed examination of those among you who find especial interest in it from one or other of the many points from which it may be approached; while for its discussion I must be content to place before you such of the more interesting and striking features of the results as may be included within such space as I may reasonably venture to wander over, keeping before me the fact that even liberal governmental printing grants have their necessary limitations. While I freely accept all blame that may be accorded to these lectures for errors of judgment in the selection of points for discussion, or for inadequacy or obscurity of treatment, I would at the same time at once ask that, for whatever interest and satisfaction may be derived from their perusal, a very large share of the credit should go to Sir Henry Gilbert, who has spent infinite pains in aiding and advising me in this work.

Section I.

SOIL SAMPLING.

The methods of soil sampling adopted at Rothamsted have been previously described to you, but it seems desirable, in a memoir which embodies such complete statistical results as will here be recorded, that the details relating to sampling should for purposes of reference be included. Indeed, it is desirable that this should be done, if only to again emphasize the general necessity of minute precautions and regular procedure in sampling any soils which either possess or may be likely to acquire an experimental history. Those who have the charge of experimental stations, and who may not have brought their minds to bear fully on the capital scientific importance of correct soil sampling, may derive useful hints from the description, while those who are already alive to the difficulties that may follow upon disregard of certain precautions will, from that very sense, bear with me. For, although attention has been directed very frequently to this matter, there is too much reason to suppose that not a little otherwise good soil work has been vitiated by reason of insufficient attention to the drawing of representative samples.

The first determinations of nitrogen in the Rothamsted soils were made by soda-lime combustion by the old platinum method, in the surface soil of the Broadbalk wheat field, as long ago as 1846; but it was soon recognized that results obtained on samples collected without careful attention to area and depth were of little value, and were, indeed, misleading. In 1856 the method of collection then and subsequently adopted was devised, and I perhaps can not do better than quote directly from Professor Warington's lecture.[1] Professor Warington says:

A frame made of stout sheet iron, in shape a rectangular prism, open at top and bottom, is driven into the soil by repeated blows of a wooden rammer, till the soil has the same level inside and outside the frame. The soil inside the frame is then cut out, and constitutes the sample of the first depth or surface soil. That the frame is accurately emptied is ascertained by trials with a wooden gauge of the same depth as the iron frame. If a sample of the next depth is to be taken, the soil is cleared away around the outside of the frame till the level is reduced to that of the bottom of the frame, the frame is then driven down again, and the former operations are repeated.

Soil sampling at Rothamsted is usually carried down to three depths, but in a good many cases it has been carried down to twelve depths. The area of the sam-

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 8, p. 39.

pling frame used for the first depth is usually 144 square inches (12 by 12 inches), a smaller frame (6 by 6 inches) being used for the succeeding depths. * * *

The iron frame has a stout rim along its upper edge to increase its strength. The best sampling frame is made of cast steel: this form of frame needs no rim. (Models of both the larger and smaller steel frames used at Rothamsted were on this occasion presented to the United States Department of Agriculture.)

When the soil sampling is carried below the first depth, care must be taken when digging around the frame that each depth of soil removed is placed by itself, so that when the pit is filled in the soil may be returned to its proper position. A record is kept of the place where the sampling was conducted, as a soil can not be accurately sampled twice in the same place.

Each sample of soil is weighed as soon as it is removed from the frame and is put into a bag by itself. When the soil reaches the laboratory it is at once broken up by hand into small pieces and laid on paper trays, which are placed on the shelves of a storeroom kept at a temperature of about 55° C. till thoroughly dry; each sample is then returned to its bag. This immediate drying of the soil at a low temperature is essential if changes in the organic matter, and especially nitrification, are to be stopped. This practice dates at Rothamsted from 1877. After drying the soil it may be stored till leisure is found for further work. Each bag is then weighed. The soil is crushed and passed through a one-fourth inch sieve; the stones that do not pass through this sieve are weighed (and subsequently described) as stones. All that passes through the sieve is thoroughly mixed and a sufficient quantity is finely powdered for analysis. Mixed samples[1] are prepared after the soil has passed through the one-fourth inch sieve or after it has reached the stage of fine powder.

This method of taking soil samples, with the exception of the adoption of the definite temperature above mentioned for drying, has been (as has already been said) in use at Rothamsted since 1856, and it is interesting here to record that between 4,000 and 5,000 individual samples of the Rothamsted soils have been collected in the fashion above described.

The depth of 9 inches fixed for sampling the surface soil is somewhat greater than would now be adopted in the light of the experience that has been gained; although it would now be obviously inexpedient to make any change at Rothamsted, since in that case future samples would not be comparable with earlier ones. But in new soil work begun elsewhere, both Sir John Lawes and Sir Henry Gilbert came to the conclusion that about 8 inches would be a fairer depth at which to mark off the surface soil from the subsoil. And, since the metric system is so widely used in scientific work, the recommendation made by them to those initiating experimental work in soil is to take the nearest round number metric approximation, and adopt a cube with the linear dimension of 0.2 meter as the unit for soil sampling. This would give to each layer of soil a depth of 7.874 inches, or practically 8 inches.

---

[1] Representing each plat and each depth.

SECTION II.

THE BROADBALK WHEAT SOILS.

SUMMARIZED HISTORY.

These plats have been under experimental cultivation since 1843, and have continuously grown wheat, the lately harvested crop of 1900 having been their fifty-seventh. The continuously unmanured plats are still giving their 12 to 13 bushels a year, while the well-manured plats are giving from 30 to 40 bushels.

The general history of the field and the practical results of the influence of the various modes of manuring upon the crops produced were very fully described and discussed by Sir Henry Gilbert in the lectures which he delivered here in 1893. This makes it unnecessary that I should take up your attention by dwelling on what may be called the above-ground or vegetative or economical effects of the various manures. It is rather on the underground results of this continuous corn growing, under so many different circumstances, that I have to discourse to you. It is necessary, however, for a discussion of the soils themselves that we should have before us a summary of the history of each plat, and as the soil analyses end for the present with the samples taken in 1893, it seems convenient to adopt, with some minor modifications, the summary given in the annual "Memoranda" issued from Rothamsted recording the results up to the end of 1893. Table 1 shows the number or special mark of each plat, a summarized history of its mode of manuring for fifty years, the average product of grain and straw for the twenty-one years, 1852–1872; for the twenty-one years, 1873–1893; for the forty-two years, 1852–1893, and also for the six years, 1889–1894.

TABLE 1.—*Broadbalk wheat plats—Historical summary of manurings and croppings to 1894.*

Plat.	Annual manuring per acre (over 50 years).	Average yield per acre.							
		21 years (1852–1872).		21 years (1873–1893).		42 years (1852–1893).		6 years (1889–1894).	
		Wheat.	Straw.	Wheat.	Straw.	Wheat.	Straw.	Wheat.	Straw.
		Bush.	*Cwt.*	*Bush.*	*Cwt.*	*Bush.*	*Cwt.*	*Bush.*	*Cwt.*
2 A	14 tons farmyard manure, commencing in 1884–1885	......	......	......	......	......	......	30¼	28⅝
2 B	14 tons farmyard manure (1843–44 and every year since)	35⅝	33[illegible]	33½	30⅝	34⅝	32¼	40⅞	38⅜
3	Unmanured continuously	14⅝	12[illegible]	11¼	8⅝	12⅝	10⅝	12⅝	9⅛
4	Unmanured continuously since 1852 (previously superphosphate and ammonium salts)	15½	13⅗	11¼	8⅕	13⅛	10⅗	13⅛	9⅛

TABLE 1.—*Broadbalk wheat plats, etc.*—Continued.

Plat.	Annual manuring per acre (over 50 years).	Average yield per acre. 21 years (1852–1872). Wheat.	21 years (1852–1872). Straw.	21 years (1873–1893). Wheat.	21 years (1873–1893). Straw.	42 years (1852–1893). Wheat.	42 years (1852–1893). Straw.	6 years (1889–1894). Wheat.	6 years (1889–1894). Straw.
		Bush.	*Cwt.*	*Bush.*	*Cwt.*	*Bush.*	*Cwt.*	*Bush.*	*Cwt.*
5 (A and B)	Potassium sulphate (200 pounds), sodium sulphate (100 pounds), magnesium sulphate (100 pounds), superphosphate (392 pounds); some dressings of ammonium salts prior to 1852	16¾	14⅝	12⅝	9¾	14¾	12¼	14¾	10¼
6 (A and B)	Potassium sulphate (200 pounds), sodium sulphate (100 pounds), magnesium sulphate (100 pounds), superphosphate (392 pounds), ammonium salts (200) pounds	26¼	24¼	21¾	18¼	24	21¼	26¼	21¾
7 (A and B)	Potassium sulphate (200 pounds), sodium sulphate (100 pounds), magnesium sulphate (100 pounds), superphosphate (392 pounds), ammonium salts (400 pounds)	35	35⅝	30¾	30¼	32¾	32⅝	34¾	33⅜
8 (A and B)	Potassium sulphate (200 pounds), sodium sulphate (100 pounds), magnesium sulphate (100 pounds), superphosphate (392 pounds), ammonium salts (600 pounds)	38½	41¼	34¾	38	36¼	39⅝	37	40⅝
9 A	Potassium sulphate (200 pounds), sodium sulphate (100 pounds), magnesium sulphate (100 pounds), superphosphate (392 pounds), sodium nitrate, formerly 550 pounds, latterly (since 1884) 275 pounds	37	42¼	32¼	30½	34¾	38¼	30	29⅝
9 B	Sodium nitrate, formerly 550 pounds, latterly (since 1884) 275 pounds	25⅞	28¼	18¾	17⅛	22⅛	22⅜	19¼	17½
10 A	Ammonium salts alone, 400 pounds yearly since 1844; mineral manure in 1844 only	22⅛	21⅜	17	13¾	19¾	17¾	16¼	13¼
10 B	Ammonium salts alone, 400 pounds yearly since 1844 (except in 1846 and 1850); mineral manure in 1844, 1848, and 1850)	25¼	24⅜	18¾	15⅝	21⅞	20	18	15½
11 (A and B)	Ammonium salts (400 pounds), superphosphate (392 pounds)	28	26¼	21	19⅜	24¼	23	21⅝	20¼
12 (A and B)	Ammonium salts (400 pounds), superphosphate (392 pounds), sodium sulphate (366½ pounds); some potassium salts in earlier years	33⅜	32⅝	26¼	24⅜	30½	28½	29⅛	25¾
13 (A and B)	Ammonium salts (400 pounds), superphosphate (392 pounds), potassium sulphate (200 pounds)	33⅞	33⅞	29	28⅝	31¼	31⅛	32⅝	31¾
14 (A and B)	Ammonium salts (400 pounds), superphosphate (392 pounds), magnesium sulphate (280 pounds); some potassium salts in earlier years	33⅝	32⅞	27¾	26	30⅝	29⅝	29¼	27⅛
15 (A and B)	Ammonium salts (400 pounds) applied in autumn; superphosphate and potassium, sodium, and magnesium salts as on plat 5. (Half this plat received rape cake in partial substitution for ammonium salts up to 1872)	33⅝	33¼	28¼	26⅝	30½	29½	32¼	30¼
16 (A and B)	1852–1864 (13 years), potassium, sodium, and magnesium salts, superphosphate, and 800 pounds ammonium salts (average produce for these 13 years, 39½ bushels grain, 46⅝ cwt. straw); 1865–1883 (19 years) unmanured (average produce for these 19 years, 14⅝ bushels grain, 12¼ cwt. straw); 1884 and since, potassium, sodium, and magnesium salts and superphosphate as on plat 5, and sodium nitrate, 550 pounds	31½	35	22⅛	22½	27⅛	28⅝	34⅛	38⅛

TABLE 1.—*Broadbalk wheat plats, etc.*—Continued.

Plat.	Annual manuring per acre (over 50 years).		Average yield per acre. 21 years (1852–1872). Wheat.	21 years (1852–1872). Straw.	21 years (1873–1893). Wheat.	21 years (1873–1893). Straw.	42 years (1852–1893). Wheat.	42 years (1852–1893). Straw.	6 years (1889–1894). Wheat.	6 years (1889–1894). Straw.
			Bush.	*Cwt.*	*Bush.*	*Cwt.*	*Bush.*	*Cwt.*	*Bush.*	*Cwt.*
17 (A and B) and 18 (A and B).	These plats in alternate years receive, the one mineral manures as on plat 5, the other ammonium salts (400 pounds), the treatment being year by year transposed. Thus, one year plat 17 receives the mineral manures and plat 18 the ammonium salts, while in the following year plat 17 receives the ammonium salts and plat 18 the mineral manures	Average of mineral years	17½	16	12¾	9⅞	15⅛	12⅞	16	12⅝
		Average of ammonium years	31⅞	31⅛	29	27⅝	30¼	29¼	29¾	27⅝
		Mean annual	24½	23½	20⅞	18⅝	22⅝	21	22⅞	19⅞
19	(Rape cake plat.) 1852–1878 (27 years), rape cake (500 pounds), ammonium salts (300 pounds), superphosphate (392 pounds); (average produce for these 27 years, 29¼ bushels grain, 27¼ cwt. straw); 1878–1882, rape cake (1,700 pounds); 1883 and since, rape cake (1,889 pounds) applied in autumn		30⅝	29⅛	25½	22¼	28	25⅝	26⅝	25⅛

MECHANICAL COMPOSITION (STONES, FINE SOIL, ETC.).

Having thus given a brief tabular history of the plats and their produce, we may return to the subject of soil sampling, giving an account of the results of the various systematic samplings that have been made of the Broadbalk soils. For the mere purpose of generalization or calculation it would no doubt suffice to give merely summarized or average results of the weights of the samples and their mechanical or physical composition; but, seeing that a vast quantity of detailed analytical work has been done the chief interest of which ultimately rests in its representation of quantities per acre, it seems desirable in a general record and discussion of such analytical data to give also an account of the detailed facts and figures which are taken by Sir Henry Gilbert as the basis of the weights of fine dry soil per acre adopted in acreage calculations of the soil constituents.

Furthermore, the various columns of figures are interesting as showing the general nature of the variations in the distribution of the stones, fine soil, moisture, etc., in the various parts of this historic field, both as regards surface soil and as regards any given layer of subsoil, and also the differences shown to exist between one layer or stratum of subsoil and another. To some of these variations, as well as to the general indications of the results, attention may be specifically directed.

The tables about to be given show the percentages of stones, fine dry soil, stubble and roots, and moisture in the sets of samples taken in the three years 1865, 1881, and 1893, while a further table is added giving a general summary of those preceding it.

TABLE 2.—*Broadbalk wheat soils (sampled in October, 1865)—Percentages of stones, fine dry soil, stubble and roots, etc., and moisture in soils as sampled.*

	First 9 inches.				Second 9 inches.				Third 9 inches.			
	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Plat 2	15.04	74.57	0.01	10.38	11.38	76.38	0.01	12.23	7.49	74.17	......	18.04
Plat 3	15.46	74.27	......	10.27	9.71	74.39	......	15.90	4.51	77.19	......	18.30
Plat 5a	14.65	76.33	......	9.02	11.07	75.31	.01	13.61	7.20	75.17	......	17.66
Plat 7a	17.54	73.74	.06	8.66	8.37	76.02	......	15.61	4.04	79.40	......	16.56
Plat 9a	18.51	72.36	.08	9.05	10.11	72.88	......	17.01	1.78	79.62	......	18.60
Plat 10a	18.06	73.67	.06	8.21	10.87	74.15	......	14.98	10.03	74.11	......	15.86
Plat 11a	18.00	73.49	.04	8.47	12.84	70.52	......	16.64	9.60	72.56	......	17.84
Plat 12a	19.29	72.61	.03	8.07	12.42	71.37	......	16.21	6.02	75.01	......	18.97
Plat 13a	16.82	73.64	.05	9.49	13.56	70.83	......	15.61	8.12	74.70	......	17.18
Plat 14a	15.84	74.58	.08	9.50	8.37	70.13	.01	21.49	7.36	73.46	0.01	19.17
Plat 16a	17.48	73.06	.06	9.40	12.98	71.17	......	15.85	4.70	74.49	......	20.81
Average, excluding plat 2	16.16	73.78	.05	9.01	11.03	72.68	......	16.29	6.34	75.57	......	18.09

a Stones retained by ¼-inch sieve. The fine dry soil includes stones passing through a ¼-inch sieve.

In 1865 eleven plats only were sampled to the depth of 27 inches. From the laboratory records it appears that in that year (1865) the samples were preserved for some time before the determinations of moisture were made, so that the percentages of moisture shown do not represent the amounts and condition of the samples as collected, a fact which of course affects the proportions of the other matters. It is nevertheless seen that the percentage of stones is highest in the surface soil, considerably lower in the second depth, and very much lower in the third. We see, moreover, considerable variation in the percentages of stones in the samples taken at the same depth from the different plats, this being especially the case in the subsoils. This irregularity in the proportion of stones and fine soil is, indeed, characteristic of the Rothamsted subsoils, and unfortunately the variations, even in different parts of the same plat, make it impossible to strike for the mineral constituents of the subsoil—such, for example, as phosphoric acid—a capital debtor and creditor account that can be analytically checked, although it is sometimes possible to do this with some degree of success in the case of the surface soil. This difficulty is, of course, much greater in the case of the "fixed" constituents of the soil—like organic nitrogen and phosphoric acid—and of the partially "fixed" constituents, like potash, than of the soluble or "migratory" constituents, like nitrates or chlorids.

TABLE 3.—*Broadbalk wheat soils (sampled in October, 1881)—Percentages of stones, fine dry soil, etc.*

	First 9 inches.				Second 9 inches.				Third 9 inches.			
	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Plat 2	12.05	68.68	0.08	19.19	12.44	69.91	0.01	17.64	9.21	70.16	0.01	20.62
Plat 3	13.17	71.08	.03	15.72	6.45	73.32	.01	20.22	1.83	75.85	.01	22.31
Plat 4	12.38	72.19	.02	15.41	3.93	76.48	.01	19.58	.85	77.18	.01	21.96
Plat 5a	13.10	70.61	.02	16.27	13.09	68.81	.01	18.09	6.45	72.57	.01	20.97
Plat 6a	13.09	69.09	.03	17.79	4.13	75.10	.01	20.76	3.14	74.82	.01	22.03
Plat 7a	13.90	69.61	.05	16.44	9.33	72.35	.01	18.31	2.15	77.86	.01	19.98
Plat 8a	15.33	68.25	.04	16.38	6.47	74.33	------	19.20	1.62	76.37	------	22.01
Plat 9a	16.08	67.50	.05	16.37	4.38	75.44	.01	20.17	1.25	75.96	.01	22.78
Plat 9b	13.90	69.73	.03	16.34	10.60	72.39	------	17.01	3.68	76.06	------	20.26
Plat 10a	14.39	69.58	.03	16.00	10.49	70.33	------	19.18	1.88	75.20	------	22.92
Plat 10b	16.69	67.45	.02	15.84	9.33	71.02	.01	19.64	8.38	69.80	------	21.82
Plat 11a	14.63	69.05	.03	16.29	7.91	71.70	------	20.39	5.51	72.58	.02	21.89
Plat 12a	16.45	67.78	.01	15.76	14.61	66.89	------	18.50	18.93	61.00	------	20.07
Plat 13a	15.33	68.47	.03	16.17	8.40	71.28	.01	20.31	4.24	73.32	.01	22.43
Plat 14a	14.93	68.15	.05	16.87	9.21	71.03	.01	19.75	4.90	70.27	.01	24.82
Plat 15a	14.40	69.15	.06	16.39	6.08	72.28	.01	21.63	3.42	71.83	.01	24.74
Plat 16a	17.41	66.89	.01	15.69	14.04	68.73	.01	17.22	11.94	67.53	------	20.53
Plat 17a	14.63	68.34	.02	17.01	13.58	65.58	.01	20.83	5.10	71.74	------	23.16
Plat 18a	16.19	67.26	.05	16.50	8.37	71.24	.01	20.38	7.04	72.10	.01	20.85
Plat 19	14.52	68.79	.02	16.67	10.15	71.08	01	18.76	7.27	70.69	------	22.04
Average, excluding plat 2	14.77	68.89	.03	16.31	8.98	71.54	.01	19.47	5.24	72.77	.01	21.98

a Stones retained by ¼-inch sieve. The fine dry soil includes stones passing through ¼-inch sieve.

Table 3 gives like results for the samples taken in 1881, though in that year as many as twenty plats were sampled. As in the case of the 1865 samples, the stones are highest in the surface soil, and decrease as we descend; again with a very great range of variation in the second and a still greater range in the third 9 inches, the fine soil, of course, varying conversely. It will be seen that the moisture is at its lowest in the surface soil, higher in the second 9 inches, and still higher in the third 9 inches. This is usually found to be the case. The differences annually vary with the preceding rainfall and other recent climatic conditions, and also according to the recent growth of vegetation, the quantity of which of course regulates the loss of water by leaf transpiration. The variations in the mode of manuring also necessarily affect the hygroscopic character of the soil; for instance, the dunged plats are far more retentive of moisture than the plats receiving chemical manures only. Thus it is usually the case that the drainpipes from the dunged plats yield no drainage water, even when the pipes from the other plats are running freely. Probably the pipes from the undunged plats run six times for once that those of the dunged plats run. Several inches of rain are required to cause the latter to run, owing to the great absorptive capacity acquired by the soil through the accumulation of organic matter from the dung.

TABLE 4.—*Broadbalk wheat soils (sampled in October, 1893)—Percentages of stones, fine dry soil, stubble and roots, etc., and moisture in soils as sampled.*

	First 9 inches.				Second 9 inches.				Third 9 inches.			
	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Plat 2a	11.97	70.96	0.02	17.05	5.90	74.22	......	19.88	2.99	74.62	......	22.39
Plat 2b	11.61	68.90	.03	19.46	9.85	72.64	......	17.51	3.52	77.53	......	18.95
Plat 3	10.76	73.54	.01	15.69	8.02	74.46	......	17.52	.56	77.74	......	21.70
Plat 4	10.54	73.86	......	15.60	7.37	73.00	......	19.63	1.06	76.27	......	22.67
Plat 5ab	13.15	70.86	.01	15.98	6.42	75.32	0.01	18.25	5.74	75.05	......	19.21
Plat 6ab	12.31	71.66	.01	16.02	2.57	78.07	......	19.36	4.12	76.78	......	19.10
Plat 7ab	12.11	71.24	.01	16.64	5.33	76.49	......	18.18	2.74	78.29	......	18.97
Plat 8ab	12.87	70.83	.01	16.29	15.31	68.09	......	16.60	13.12	68.55	......	18.33
Plat 9a	12.28	71.25	.01	16.46	5.74	76.44	......	17.81	.61	77.49	......	21.90
Plat 9b	11.23	72.44	.01	16.32	11.13	73.77	......	15.10	8.23	73.26	......	18.51
Plat 10a	13.86	70.27	......	15.87	12.27	67.94	......	19.79	1.59	74.99	......	23.42
Plat 10b	12.14	71.60	......	16.26	9.13	71.65	......	19.22	2.44	74.68	......	22.88
Plat 11ab	14.40	69.59	......	16.01	17.78	64.20	......	18.02	9.66	69.76	......	20.58
Plat 12ab	14.34	69.47	......	16.19	8.27	70.17	......	21.56	5.20	71.88	......	22.92
Plat 13ab	13.97	69.52	.01	16.50	17.49	64.07	......	18.44	6.21	73.19	......	20.60
Plat 14ab	13.32	70.36	......	16.32	9.12	68.94	......	21.94	9.71	68.46	......	21.83
Plat 15ab	14.31	69.52	.01	16.16	11.88	66.74	......	21.38	3.11	72.28	......	24.61
Plat 16ab	13.52	70.31	......	16.17	7.96	69.91	......	22.13	10.28	67.77	......	21.95
Plat 17ab	14.26	70.26	.01	15.47	13.94	66.63	.01	19.42	4.69	74.17	......	21.14
Plat 18ab	14.01	70.42	.01	15.56	8.10	69.90	......	22.00	4.37	72.54	......	23.09
Plat 19	14.07	70.40	.01	15.53	5.64	74.28	......	20.08	4.91	70.14	......	24.95
Average, excluding plats 2a and 2b	13.02	70.92	.01	16.05	9.66	71.05	.01	19.28	5.18	73.33	......	21.49

	Fourth 9 inches.				Fifth 9 inches.				Sixth 9 inches.			
	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Plat 5ab	0.15	77.67	......	22.18	0.95	78.33	......	20.72	3.00	75.28	......	21.72
Plat 6ab	1.38	80.72	......	17.90	.35	80.80	......	18.85	.44	80.93	......	18.63
Plat 7ab	4.77	77.11	......	18.12	13.46	69.59	......	16.95	17.00	66.92	......	16.08
Plat 8ab	6.56	73.91	......	19.53	.76	79.94	......	19.30	14.98	69.84	......	15.18
Plat 11ab	7.28	71.39	......	21.33	5.75	72.87	......	21.38	12.16	68.79	......	19.05
Plat 12ab	2.11	76.06	......	21.83	3.26	75.69	......	21.05	10.09	70.66	......	19.24
Plat 13ab	4.13	74.06	......	21.81	1.41	78.64	......	19.95	2.98	74.82	......	22.20
Plat 14ab	5.74	75.78	......	18.48	.67	76.48	......	22.85	1.00	75.22	......	23.78
Plat 15ab	3.96	73.89	......	22.15	.27	77.49	......	22.24	.47	79.53	......	20.00
Plat 16ab	19.86	59.49	......	20.64	1.22	72.18	......	26.60	3.24	72.13	......	24.63
Plat 17ab	6.29	71.87	......	21.84	6.17	69.51	......	24.32	8.01	67.84	......	24.15
Plat 18ab	10.41	68.55	......	21.04	22.89	59.61	......	17.50	.41	76.45	......	23.14
Average	6.05	73.38	......	20.57	4.76	74.26	......	20.98	6.15	73.20	......	20.65

TABLE 4.—*Broadbalk wheat soils, etc.*—Continued.

	Seventh 9 inches.				Eighth 9 inches.			
	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Plat 5ab	1.44	74.18	......	24.38	2.72	74.40	......	22.88
Plat 6ab	13.75	70.28	......	15.97	13.59	75.36	......	11.06
Plat 7ab	.55	82.07	......	17.38	1.79	78.73	......	19.48
Plat 8ab	5.19	77.78	......	17.03	4.15	78.37	......	17.48
Plat 11ab	12.92	70.31	......	16.77	8.31	73.84	......	17.85
Plat 12ab	15.62	66.17	......	18.21	21.95	56.63	......	21.42
Plat 13ab	3.43	70.75	......	25.82	1.99	73.82	......	24.19
Plat 14ab	3.64	73.51	......	22.85	3.47	72.95	......	23.58
Plat 15ab	10.63	72.39	......	16.98	7.43	75.66	......	16.91
Plat 16ab	1.97	74.17	......	23.86	2.32	72.50	......	25.18
Plat 17ab	19.77	59.35	......	20.88	4.91	74.81	......	20.28
Plat 18ab	4.93	76.11	......	18.96	.87	80.81	......	18.32
Average	7.82	72.26	......	19.92	6.12	73.99	......	19.89

	Ninth 9 inches.				Tenth 9 inches.			
	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.	Total stones. *a*	Fine dry soil.	Stubble, roots, etc.	Moisture.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Plat 5ab	3.98	72.81	......	23.21	12.34	67.33	......	20.33
Plat 6ab	3.17	82.26	......	14.57	3.19	79.68	......	17.13
Plat 7ab	3.05	77.73	......	19.22	4.47	77.44	......	18 09
Plat 8ab	.77	82.51	......	16.72	.10	84.79	......	15.11
Average	2.74	78.83	......	18.43	5.03	77.31	......	17.66

a Stones retained by ¼-inch sieve. The fine dry soil includes stones passing through ¼-inch sieve.

Table 4 gives like results for the much more complete set of samples drawn in 1893. In that year the sampling was not confined to 27 inches, but was carried down in a great many cases—in successive depths of 9 inches—to 72 inches or 6 feet, while in the case of 4 plats a depth of 90 inches or 7½ feet was reached. And here I must make a public confession. During the sampling of 1893, Sir Henry Gilbert was here in America lecturing, and Sir John Lawes was superintending the work of sampling at Rothamsted. I happened to go to see him while the pits excavated for sampling the wheat plats were open, the full depth of 90 inches having been reached only in four cases. I was much interested in the sampling, as a set of the samples was promised to me for investigation in regard to the phosphoric acid and potash constituents, by a process which I had then recently applied, with very interesting results, to the examination of the barley soils in Hoos field. I was much struck with the great variations shown by the subsoils of the wheat plats in their lowermost depths. The lower subsoils, at corresponding depths, were in some cases mere chalk, in others mixtures of clay and chalk, and in others of chalk, clay, and gravel; and this lack of any kind of apparent uniformity so low down made it obvious that the lower samples were likely to be of very little value for the purpose of comparison of their fixed mineral contents or of their organic nitrogen. My mind was probably mainly concentrated upon the phosphoric acid and potash problems which I was myself about to be allowed to investigate, and it appeared to me that from that point of view there was not much interest in the samples below the second or third depth. Sir John Lawes pointed out that this would not apply in anything like the same degree to diffusible constituents, e. g., nitrates. It appeared to me, however, to be very unlikely that even the migratory constituents would present much interest at a depth of 7½ feet, for at that depth, or even considerably short of it, it seemed natural to suppose that the subsoil contents washed down from the surface would have not merely descended, but would have also diffused laterally to such an increasing extent that the subsoils would surely have their proper soluble contents merged into one another; for the wheat plats, although something like half an acre in area, are arranged in long strips parallel to one another, and not in squares. This view I was rash enough to express pretty confidently, with the result that Sir John Lawes—who, I believe, inwardly felt a like conviction—decided not to spend further time and labor in completing the sampling of the deeper subsoils, especially as the season was getting late and he was anxious to get the wheat sown. Now it happens that my view as to the lateral diffusibility of the nitrates, even at so great a depth as 7½ feet, was incorrect, their downward settlement being much more vertical than I had anticipated; and the results of subsequent analyses of even the deepest subsoils by Sir Henry Gilbert were such as to make it a matter of regret that the original plan of sampling to 90 inches throughout the whole series of plats was not carried out. But for my unlucky visit, Sir John—even, perhaps, a little in the face of his own inclination—would have completed the sampling plan that he had prearranged with Sir Henry Gilbert, who, I am afraid, does not to this day quite forgive me. I now publicly express my sorrow for the gaps which, through my fault, will be found in certain interesting tables which we shall have to deal with by-and-by.

TABLE 5.—*Broadbalk wheat soils sampled in October, 1865; October, 1881, and October, 1893—Percentages of stones, fine dry soil, stubble and roots, etc., and moisture in soils as sampled.*

SUMMARY, EXCLUDING DUNGED PLATS.

Depth.	Number of plats.	Total stones.*a*	Fine dry soil.	Stubble, roots, etc.	Moisture.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Samples collected October 2-9, 1865:					
First 9 inches	10	16.16	73.78	0.05	9.01
Second 9 inches	10	11.03	72.68	----------	16.29
Third 9 inches	10	6.34	75.57	----------	18.09
Samples collected October 10-18, 1881:					
First 9 inches	19	14.77	68.89	.03	16.31
Second 9 inches	19	8.98	71.54	.01	19.47
Third 9 inches	19	5.24	72.77	.01	21.98
Samples collected October 13-21, 1893:					
First 9 inches	19	13.02	70.92	.01	16.05
Second 9 inches	19	9.66	71.05	.01	19.28
Third 9 inches	19	5.18	73.33	----------	21.49
Fourth 9 inches	12	6.05	73.38	----------	20.57
Fifth 9 inches	12	4.76	74.26	----------	20.98
Sixth 9 inches	12	6.15	73.20	----------	20.65
Seventh 9 inches	12	7.82	72.26	----------	19.92
Eighth 9 inches	12	6.12	73.99	----------	19.89
Ninth 9 inches	4	2.74	78.83	----------	18.43
Tenth 9 inches	4	5.03	77.31	----------	17.66

a Stones retained by ¼-inch sieve. The fine dry soil includes stones passing through ¼-inch sieve.

The short summary given in Table 5, especially in the 1893 division, shows at a glance the average composition of all the plats, excluding the dunged plats, at the various depths. There is a general though not uniform decline in the proportion of stones as we go deeper, and, of course, a corresponding increase in fine soil, together with a general increase downward in the moisture retained by the soil, though in the last depths there is a decrease. The variations are, for a considerable depth, due, no doubt, mainly to the causes of weather, vegetation, etc., already alluded to, but in the lower depths the varying proximity of the underlying chalk must to some extent afford a varying facilitation for the passage away of drainage water. Thus far for the mere percentage mechanical composition of the soil, based upon the arbitrary division into stones retained by a one-fourth-inch sieve and fine soil.

We have now to go into the very important question of the weights per acre represented by the samples taken in various years from the various plats and at various depths. The whole of the figures relating to the great number of samples taken need not be given, nor would their record serve any useful purpose, but it appears important to give a résumé of the hitherto unpublished data on which are based the acreage weights now adopted at Rothamsted, and Sir Henry Gilbert has very kindly furnished me with such a résumé.

The methods of sampling and weighing and of sifting and dividing the samples into stones and fine soil have already been described. In comparing the results obtained in the 1865 and 1881 samples it was noticed many years ago that the 1865 samples representing the first 9 inches were approximately one-tenth lighter in weight than those of

1881. After a careful study at the time it was considered by Sir John Lawes and Sir Henry Gilbert that the lighter weights of 1865 were more probably correctly representative of the first 9 inches, and that the 1881 samples had included, in the actual 9 inches taken, more than the first 9 normal inches of soil; in fact, that the quantity taken on the original weight represented more nearly 10 inches of real depth than 9 inches, or that it included about 1 inch too much of subsoil. Accordingly, after analysis of the soils, the estimates per acre of the nitrogen, for example, in the 1881 samples, were calculated on the assumption that the weights should have been approximately one-tenth less, a deduction of one-tenth being made from the originally indicated acreage weight of the soil. But more recently, when the weights of the 1893 samples were available for comparison, it was found that the average weights of the 1881 and 1893 samples of the first 9 inches agreed, both being very sensibly above those of 1865. A careful study of the climatic features of the three individual seasons, both before and after the removal of their respective crops, and of the probable condition of the land as affected thereby, together with the notes that had been kept relating to the mechanical operations to which the land had been subjected, led to the conclusion that in 1865 the surface soil was in a lighter condition than in either 1881 or 1893, and that probably the weights were more normal in the two later years. After much tabulation and much thought and calculation as to the effects of assimilating the weights of 1865 with those of 1881 and 1893, it was found that no inconsistency was introduced and that the truth was more probably arrived at by correcting, on this assumption, the estimates derived from the weights of 1865 than by altering, as had previously been done, the estimates for 1881. As regarded the subsoils, there seemed to be little reason for supposing that the weights would materially alter from period to period, and, after careful correlation of all the details, it was decided to take a fixed weight of fine, dry soil for each depth at each of the three periods, this being found by taking the mean of all the determinations in the three or the two years, as the case might be.

There were considerable variations in the weights of fine, dry soil in the samples from the different plats in one and the same year, which were largely attributable to the varying amounts of stones; but comparing the averages for all the plats of one year with those of the others the differences were comparatively immaterial.

Except, therefore, in the case of the plats receiving large quantities of organic matter, such as farmyard manure or rape cake, there has now been adopted, for the three years, a uniform average weight of fine dry soil for the first 9 inches, and also a uniform weight per acre of fine dry soil for each depth below the first 9 inches, including, in the case of the subsoils, those of the dung and rape-cake plats. As the estimates of weight of soil per acre now adopted will continue to be used at Rothamsted until any further experience indicates the propriety of any modifications, it is desirable that the data from which these estimates are derived should be published for future reference, and they are therefore embodied in the following table:

TABLE 6.—*Broadbalk wheat soils—Résumé of data and weights of fine dry soil per acre adopted for all plats sampled, and for all depths taken in 1865, 1881, and 1893 (excepting for the first 9 inches of plats 2a, 2b, and 19, for which see separate table).*

[It will be seen that in the case of the first depth the results for plat 2 and 19 are not brought in in taking the average for the other plats, but that for each depth below the first the results for plats 2 and 19 are brought in, and that a uniform weight is adopted for each depth for each of the three years, 1865, 1881, and 1893.]

	Year.	Number of plats.	Number of samples.	Stones retained by ¼-inch sieve.	Average weight per acre. Fine soil (dry) passing ¼-inch sieve.	Total fine dry soil and stones.	Moisture.	Total soil as sampled in the field.
First 9 inches:								
All plats sampled, excluding plat 2—				*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Actual	1865	10	80	534,971	2,297,896	2,832,867	280,924	3,115,221
Adopted	1865	10	174	523,549	2,592,621	3,116,170	601,564	3,718,565
′ ll plats sampled, excluding 2 and 19	1881	18	108	547,749	2,557,170	3,104,919	602,073	3,708,177
	1893	18	66	483,950	2,650,631	3,134,581	600,731	3,735,563
Average, 1881 and 1893	......	....	174	523,549	2,592,621	3,116,170	601,564	3,718,565
Second 9 inches:								
All plats sampled, excluding 2 and 19	1881	18	108	338,252	2,708,505	3,046.757	737,601	3.784,632
	1893	18	66	357,278	2,567,100	2,924,378	695,430	3,619,879
Average, 1881 and 1893	......	....	174	345,469	2,654,869	3,000,338	721,605	3,722,139
All plats sampled, including 2 and 19	1881	20	120	347,510	2,706,473	3,053,983	733,232	3,787,500
	1893	21	77	343,067	2,579,859	2,922,926	694,659	3,617,652
Average, 1881 and 1893	......	....	197	345,773	2,656,984	3,002.757	718,155	3,721,113
All plats, including 2	1865	11	88	410,015	2,703,417	3,113,432	590,189	3,703,714
All plats, including 2 and 19	1881	20	120	347,510	2,706,473	3,053.983	733,232	3,787,500
Do	1893	21	77	343,067	2,579,859	2,922,926	694,659	3,617,652
Average, 1865, 1881, and 1893	......	....	285	365,609	2,671,321	3,036,930	678,643	3,715,740
Third 9 inches:								
All plats sampled, excluding 2 and 19	1881	18	108	194,415	2,763,164	2,957,579	832,173	3,790,004
	1893	18	66	196,121	2,777,540	2,973,661	803,147	3,776,839
Average, 1881 and 1893	......	....	174	195,062	2,768,617	2,963,679	821,163	3,785,010
All plats, including 2 and 19	1881	20	120	205,828	2,750,600	2,956,428	828,831	3,785,506
	1893	21	77	188,555	2,780,895	2,969,450	807,363	3,776,842
Average, 1881 and 1893	......	....	197	199,077	2,762,441	2,961,518	820,440	3,782,120
All plats sampled, including 2	1865	11	88	243,973	2,856,554	3,100,527	684,955	3,785,513
All plats, including 2 and 19	1881	20	120	205,828	2,750,600	2,956,428	828,831	3,785,506
Do	1893	21	77	188,555	2,780,895	2,969,450	807,363	3,776,842
Average, 1865, 1881, and 1893	......	....	285	212,939	2,791,501	3,004,440	778,606	3,783,167

TABLE 6.—*Broadbalk wheat soils, etc.*—Continued.

SUMMARY OF ADOPTED WEIGHTS, ETC.

	Depth.	Number of plats.	Number of samples.	Stones retained by ¼-inch sieve.	Average weight per acre.			
					Fine soil (dry) passing ¼-inch sieve.	Total fine, dry soil and stones.	Moisture.	Total soil as sampled in the field.
				Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Average of—108 samples in 1881 and 66 in 1893	First	....	174	523,549	2,592,621	3,116,170	601,564	3,718,565
88 samples in 1865, 120 in 1881, and 77 in 1893	Second	....	285	365,609	2,671,321	3,036,930	678,643	3,715,740
Do	Third	....	285	212,939	2,791,501	3,004,440	778,606	3,783,167
All samples in 1893	Fourth	12	24	228,690	2,783,485	3,012,175	778,435	3,790,628
Do	Fifth	12	24	186,492	2,865,549	3,052,041	807,104	3,859,144
Do	Sixth	12	24	237,765	2,836,890	3,074,655	797,535	3,872,189
Do	Seventh	12	24	298,341	2,746,319	3,044,660	752,434	3,797,094
Mean of 6th and 8th depths (adopted)	....	..	....	238,843	2,852,599	3,091,442	781,712	3,873,154
All samples in 1893	Eighth	12	24	239,920	2,868,308	3,108,228	765,889	3,874,118
Do	Ninth	4	8	102,955	3,003,479	3,106,434	700,142	3,807,076
Do	Tenth	4	8	190,915	3,001,755	3,192,670	683,149	3,875,819

In the case of the plats receiving annually large quantities of organic matter in the form of dung or rape cake the soil necessarily becomes more bulky or porous and absorbent, and therefore lighter as regards the surface soil. Table 6 shows the determined weights of the dunged plats, 2a and 2b, and of the rape-cake plat at different periods, and also their calculated weights based on the assumption of an average yearly decrease in weight corresponding to increment of organic matter. Plat 2a, it will be remembered, has received 14 tons of farmyard manure every year since 1884—that is to say, for only nine years previously to the 1893 sampling—while plat 2b had received 14 tons of farmyard manure every year for fifty years. Plat 19 has for many years received about 16 hundredweight of ground rape cake per annum.

TABLE 7.—*Broadbalk wheat soils, actual and calculated weights per acre of fine dry soil, of plats 2a, 2b, and 19, at different depths (first 9 inches).*

Year of sampling.	Actual weight of fine dry soil per acre.	Assuming 2,592,621 pounds in 1884 for 2a, and in 1843 for 2b, and in 1878 for 19 (as adopted for all dates for all plats except 2 and 19).	Number of years between starting point and each sampling.	Reduction of weight, if at same rate per annum.	Calculated weight of fine dry soil per acre at each date (starting-point weight less assumed reduction over successive periods).	Actual (+ or —) calculated weight.
Plat 2a:	*Pounds.*	*Pounds.*	*Years.*	*Pounds.*	*Pounds.*	*Pounds.*
1843	(*a*)	2,592,621				
1893	2,510,185	2,510,185				
Difference in 9 years		82,436				
Difference per annum		9,160				
Plat 2b:						
1843	(*a*)	2,592,621			2,592,621	
1865	*b* 2,420,363		22	113,841	2,478,780	−58,417
1881	2,456,509		38	196,635	2,395,986	+60,523
1893	2,333,891	2,333,891	50	258,730	2,333,891	
Difference in 50 years		258,730				
Difference per annum		5,174.6				
Plat 19:						
1878 *b*	(*a*)	2,592,621				
1881 *c*	2,462,780		3	2,536	2,590,085	
1893	2,579,942	2,579,942	15	12,679	2,579,942	
Difference in 15 years		12,679				
Difference per annum		845.3				

a Not sampled.
b All 1865 first 9 inches assumed to be one-ninth too low; hence actual weight, 2,178,327 pounds, + one-ninth (242,036 pounds) = 2,420,363 pounds, assumed corrected weight.
c 1878, the commencement of a large increase in the amount of rape cake applied per annum is adopted as the starting point in this case.

The following table (Table 8), abstracted from the foregoing tables, gives at a glance the final adopted weights:

TABLE 8.—*Weights per acre of fine dry soil adopted for the Broadbalk wheat plats.*

[Extracted from Tables 6 and 7.]

	Pounds.
First 9 inches:	
For all plats, excepting 2a, 2b, and 19 for each year, 1865, 1881, and 1893	2,592,621
For plat 2a in 1893	2,510,185
For plat 2b in 1865	2,478,780
For plat 2b in 1881	2,395,986
For plat 2b in 1893	2,333,891
For plat 19 in 1893	2,579,942
Second 9 inches:	
For all plats in each year	2,671,321
Third 9 inches:	
For all plats in each year	2,791.501
Lower depths, for all plats:	
Fourth 9 inches	2,783,485
Fifth 9 inches	2,865,549
Sixth 9 inches	2,836,890
Seventh 9 inches	2,852,599
Eighth 9 inches	2,868,308
Ninth 9 inches	3,003,479
Tenth 9 inches	3,001,755

SAMPLES TAKEN IN 1893.

These samples, you may be reminded, were drawn at the close of the fiftieth experimental year of continuous wheat growing on the same series of plats. As the results of the examination of this series of samples are new, and as they possess, on account of the greater age of the experiments, more interest than the earlier samples, they may be allowed to have the first claim on our attention. They will subsequently be considered in relation to those of the earlier samples.

TOTAL NITROGEN AND ORGANIC CARBON (GENERAL DISCUSSION AND FULL STATEMENT OF ANALYTICAL RESULTS).

The most important element in the soil, because the most expensive one to supply, and therefore the one we are most anxious to conserve, is the nitrogen. We will, therefore, consider in the first place the results of the determinations of nitrogen in the samples representing the soils and subsoils of the various plats.

It is here necessary to explain to those who are not practical chemists that there are two methods in general use for the determination of nitrogen in such bodies as soil. Much the older, and formerly the almost universally adopted, method was that known as the soda-lime combustion method. All the earlier determinations at Rothamsted were made by this method of analysis. In the last few years another method, one of "moist combustion" in boiling sulphuric acid, has arisen, known, from the name of its inventor, as the Kjeldahl method. For practical commercial purposes, such as the examination of manures, where accuracy in small decimal percentage places is not sought, both methods give substantially the same results. It is, however, now largely conceded that the Kjeldahl process, properly modified, is the more trustworthy; and, from its cleanliness, convenience, and simplicity, it has in England and in Germany now practically supplanted the soda-lime method, and, I understand, has also to a large extent done so in America, although I believe your chemists still recognize the soda-lime method as an alternative official process.

The 1893 wheat-soil samples have all been examined by both processes, and as there is throughout a slight difference in the results, it is considered important that both should be recorded, for although, as will presently appear, it is desirable to accept the Kjeldahl results as the more satisfactory, it is, on the other hand, important to preserve the soda-lime results for comparison with those of the analyses of the earlier series of samples, which were made by the soda-lime method. It is, moreover, interesting to those who are practical agricultural chemists to see the nature and range of the variations between the two sets of results. These are set out in Table 9. The nitric nitrogen is also added separately.

TABLE 9.—*Broadbalk wheat soils, sampled in October, 1893—Percentage of* NITROGEN *in fine dry soil, as determined, respectively, by the soda-lime method and by the Kjeldahl method; also the percentage of "nitric" nitrogen (nitrogen existing in the form of nitrates).*

	First 9 inches.				Second 9 inches.			
	Total nitrogen.			"Nitric" nitrogen.	Total nitrogen.			"Nitric" nitrogen.
	By soda-lime.	By Kjeldahl.	Kjeldahl (+) or (−) soda-lime.		By soda-lime.	By Kjeldahl.	Kjeldahl (+) or (—) soda-lime.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Plat 2a	0.1520	0.1628	+0.0108	0.000943	0.0761	0.0811	+0.0051	0.000848
Plat 2b	.2132	.2207	+ .0075	.000451	.0712	.0767	+ .0055	.001698
Plat 3	.0940	.0992	+ .0052	.000372	.0696	.0730	+ .0034	.000345
Plat 4	.0906	.0982	+ .0076	.000307	.0670	.0783	+ .0113	.000263
Plat 5	.0971	.1013	+ .0042	.000406	.0684	.0739	+ .0055	.000238
Plat 6	.1076	.1107	+ .0031	.000545	.0671	.0720	+ .0049	.000477
Plat 7	.1146	.1222	+ .0076	.000577	.0598	.0681	+ .0083	.000719
Plat 8	.1167	.1188	+ .0021	.000671	.0696	.0752	+ .0056	.001092
Plat 9a	.1116	.1189	+ .0073	.000641	.0765	.0849	+ .0084	.000720
Plat 9b	.1058	.1094	+ .0036	.000428	.0778	.0799	+ .0021	.001305
Plat 10a	.1002	.1069	+ .0067	.000483	.0789	.0817	+ .0028	.000952
Plat 10b	.1029	.1064	+ .0035	.000364	.0765	.0820	+ .0055	.001088
Plat 11	.1119	.1131	+ .0012	.000450	.0747	.0812	+ .0065	.000920
Plat 12	.1110	.1194	+ .0084	.000546	.0791	.0840	+ .0049	.000954
Plat 13	.1088	.1162	+ .0074	.000537	.0686	.0757	+ .0071	.000979
Plat 14	.1204	.1250	+ .0046	.000516	.0748	.0804	+ .0056	.001160
Plat 15	.1188	.1234	+ .0046	.000386	.0809	.0842	+ .0033	.000700
Plat 16	.1110	.1177	+ .0067	.000524	.0708	.0783	+ .0075	.001594
Plat 17	.1117	.1174	+ .0057	.000470	.0731	.0777	+ .0046	.001037
Plat 18	.1204	.1232	+ .0028	.000449	.0701	.0793	+ .0092	.001553
Plat 19	.1309	.1348	+ .0039	.000855	.0776	.0794	+ .0018	.000912
Average, excluding 2a and 2b	.1098	.1149	+ .0051	.000501	....	....	....	....
Average, all plats	.1167	.1222	+ .0055	.000520	.0728	.0784	+ .0056	.000931

	Third 9 inches.				Fourth 9 inches.			
	Total nitrogen.			"Nitric" nitrogen.	Total nitrogen.			"Nitric" nitrogen.
	By soda-lime.	By Kjeldahl.	Kjeldahl (+) or (—) soda-lime.		By soda-lime.	By Kjeldahl.	Kjeldahl (+) or (−) soda-lime.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Plat 2a	0.0645	0.0660	+0.0015	0.000368	....	....	....	....
Plat 2b	.0628	.0656	+ .0028	.000439	....	....	....	....
Plat 3	.0594	.0651	+ .0057	.000098	....	....	....	....
Plat 4	.0573	.0644	+ .0071	.000076	....	....	....	....
Plat 5	.0560	.0645	+ .0085	.000080	0.0458	0.0524	+0.0066	0.000034
Plat 6	.0558	.0628	+ .0070	.000208	.0448	.0469	+ .0021	.000107
Plat 7	.0527	.0583	+ .0056	.000306	.0501	.0466	− .0035	.000191
Plat 8	.0587	.0630	+ .0043	.000312	.0567	.0546	− .0021	.000313
Plat 9a	.0609	.0696	+ .0087	.000240	....	....	....	....
Plat 9b	.0649	.0690	+ .0041	.000558	....	....	....	....
Plat 10a	.0678	.0706	+ .0028	.000403	....	....	....	....
Plat 10b	.0682	.0696	+ .0014	.000501	....	....	....	....
Plat 11	.0622	.0672	+ .0050	.000533	.0438	.0585	+ .0147	.000419
Plat 12	.0676	.0733	+ .0057	.000435	.0569	.0634	+ .0065	.000268
Plat 13	.0566	.0650	+ .0084	.000338	.0514	.0528	+ .0014	.000168
Plat 14	.0635	.0650	+ .0015	.000422	.0399	.0441	+ .0042	.000246
Plat 15	.0578	.0693	+ .0015	.000377	.0390	.0441	+ .0051	.000234
Plat 16	.0606	.0655	+ .0049	.000744	0463	.0521	+ .0058	.000468
Plat 17	.0606	.0671	+ .0065	.000306	.0468	.0497	+ .0029	.000103
Plat 18	.0606	.0663	+ .0057	.000229	.0467	.0481	+ .0014	.000121
Plat 19	.0697	.0719	+ .0022	.000508	....	....	....	....
Average, all plats	.0613	.0666	+ .0053	.000356	.0474	.0511	+ .0037	.000223

TABLE 9.—*Broadbalk wheat soils, etc.*—Continued.

	Fifth 9 inches.				Sixth 9 inches.			
	Total nitrogen.			"Nitric" nitrogen.	Total nitrogen.			"Nitric" nitrogen.
	By soda-lime.	By Kjeldahl.	Kjeldahl (+) or (—) soda-lime.		By soda lime.	By Kjeldahl.	Kjeldahl (+) or (—) soda-lime.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Plat 5	0.0406	0.0442	+0.0036	0.000035	0.0497	0.0569	+0.0072	0.000025
Plat 6	.0462	.0497	+ .0035	.000121	.0456	.0463	+ .0007	.000131
Plat 7	.0425	.0468	+ .0043	.000162	.0341	.0348	+ .0007	.000155
Plat 8	.0489	.0497	+ .0008	.000297	.0409	.0409	.0000	.000263
Plat 11	.0470	.0491	+ .0021	.000300	.0404	.0404	.0000	.000177
Plat 12	.0479	.0493	+ .0014	.000204	.0413	.0477	+ .0064	.000178
Plat 13	.0453	.0517	+ .0064	.000123	.0417	.0467	+ .0050	.000134
Plat 14	.0386	.0444	+ .0058	.000213	.0409	.0438	+ .0029	.000190
Plat 15	.0407	.0458	+ .0051	.000189	.0297	.0333	+ .0036	.000152
Plat 16	.0484	.0543	+ .0059	.000273	.0413	.0442	+ .0029	.000210
Plat 17	.0441	.0449	+ .0008	.000064	.0334	.0413	+ .0079	.000061
Plat 18	.0346	.0360	+ .0014	.000102	.0317	.0397	+ .0080	.000058
Average, all plats	.0437	.0472	+ .0035	.000174	.0392	.0430	+ .0038	.000144

	Seventh 9 inches.				Eighth 9 inches.			
	Total nitrogen.			"Nitric" nitrogen.	Total nitrogen.			"Nitric" nitrogen.
	By soda-lime.	By Kjeldahl.	Kjeldahl (+) or (—) soda-lime.		By soda-lime.	By Kjeldahl.	Kjeldahl (+) or (—) soda-lime.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent*	*Per cent.*
Plat 5	0.0584	0.0591	+0.0007	0.000036	0.0561	0.0568	+0.0007	0.000032
Plat 6	.0401	.0400	— .0001	.000114	.0315	.0322	+ .0007	.000066
Plat 7	.0416	.0416	.0000	.000158	.0348	.0377	+ .0029	.000140
Plat 8	.0428	.0442	+ .0014	.000280	.0378	.0384	+ .0006	.000265
Plat 11	.0310	.0366	+ .0056	.000157	.0342	.0371	+ .0029	.000213
Plat 12	.0380	.0423	— .0043	.000188	.0295	.0330	+ .0035	.000185
Plat 13	.0427	.0471	+ .0044	.000124	.0433	.0493	+ .0060	.000124
Plat 14	.0397	.0454	+ .0057	.000197	.0470	.0493	+ .0023	.000237
Plat 15	.0318	.0353	+ .0035	.000178	.0295	.0303	+ .0008	.000133
Plat 16	.0396	.0454	+ .0058	.000191	.0435	.0479	+ .0044	.000219
Plat 17	.0297	.0348	+ .0051	.000048	.0319	.0333	+ .0014	.000060
Plat 18	.0282	.0324	+ .0042	.000050	.0307	.0301	— .0006	.000050
Average, all plats	.0386	.0420	+ .0034	.000050	.0375	.0396	+ .0021	.000144

	Ninth 9 inches.				Tenth 9 inches.			
	Total nitrogen.			"Nitric" nitrogen.	Total nitrogen.			"Nitric" nitrogen.
	By soda-lime.	By Kjeldahl	Kjeldahl (+) or (—) soda lime.		By soda-lime.	By Kjeldahl.	Kjeldahl (+) or (—) soda-lime.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Plat 5	0.0487	0.0566	+0.0079	0.000029	0.0525	0.0571	+0.0046	0.000019
Plat 6	.0325	.0325	.0000	.000082	.0311	.0332	+ .0021	.000072
Plat 7	.0302	.0355	+ .0053	.000143	.0332	.0332	.0000	.000146
Plat 8	.0318	.0318	.0000	.000204	.0265	.0265	.0000	.000188
Average, all plats	.0358	.0391	+ .0033	.000115	.0358	.0375	+ .0017	.000106

TABLE 10.—*Broadbalk wheat soils, sampled in October, 1893—Percentages of* NITROGEN *in fine dry soil, as determined, respectively, by the soda-lime method and by the Kjeldahl method: also the percentages of "nitric" nitrogen (nitrogen existing in the form of nitrates).*

[Summary of preceding results in Table 9—averages of all plats sampled at each depth.]

Depth.	Number of plats.	Total nitrogen.		Kjeldahl (+) or (—) soda-lime.	"Nitric" nitrogen.
		By soda-lime.	By Kjeldahl.		
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
First 9 inches (excluding 2a and 2b)	19	0.1098	0.1149	+0.0051	0.000501
First 9 inches (all plats)	21	.1167	.1222	+ .0055	.000520
Second 9 inches	21	.0728	.0784	+ .0056	.000931
Third 9 inches	21	.0613	.0666	+ .0053	.000356
Fourth 9 inches	12	.0474	.0511	+ .0037	.000223
Fifth 9 inches	12	.0437	.0472	+ .0035	.000174
Sixth 9 inches	12	.0392	.0430	+ .0038	.000144
Seventh 9 inches	12	.0386	.0420	+ .0034	.000143
Eighth 9 inches	12	.0375	.0396	+ .0021	.000144
Ninth 9 inches	4	.0358	.0391	+ .0033	.000115
Tenth 9 inches	4	.0358	.0375	+ .0017	.000106

It will be seen that in almost every individual instance, and always in the case of the average results for each depth of soil, the Kjeldahl method gives a higher percentage of nitrogen than the soda-lime method. The actual difference is greater in the case of the higher than of the lower depths. Reckoned, however, in percentage on the total nitrogen obtained, the deficiency by the soda-lime method is on the average considerably less in the case of the samples of the first depth (which, as will be seen hereafter, contain not only more nitrogen, but also more carbon, and a higher ratio of carbon to nitrogen) than in the lower or subsoil depths. But, with some marked exceptions, the relative deficiency of the soda-lime method, though higher in the subsoils than in the surface soils, is on the average fairly uniform from depth to depth, and averages between 7 and 8 per cent of the total nitrogen. A comparison of the column of the summary table (Table 10), showing the greater amount of nitrogen found by the Kjeldahl method, with the column showing the nitrogen existing as nitrates, will show that the higher results can not be accounted for by more complete determination of the nitric nitrogen by the Kjeldahl method; nor do the figures showing the relation of carbon to nitrogen (to be hereafter given) indicate any deficiency of carbon for the decomposition of the organic nitrogenous compounds by the soda-lime. The conclusion is rather that the action of the liquid acid in breaking up the organic nitrogenous compounds, in order to convert the nitrogen into ammonia, in the Kjeldahl process, is more complete than is the action of dry heat on the mixture of soda-lime and soil.

On the whole it appears that the Kjeldahl results should be adopted as most correctly indicating the actual nitrogen in the 1893 samples—though the soda-lime results will be more properly taken in any comparison which it is desired to draw between these and the 1865 or 1881 samples. For the present, therefore, we will direct our attention to the nitrogen figures as obtained by the Kjeldahl method.

The following tables (Tables 11 and 12) show, both in percentages (parts per million in the case of the nitrogen in nitrates) and as pounds per acre, for each plat and for every depth of soil examined, the total nitrogen, the nitrogen as nitrates, and the organic carbon, together with the ratio of carbon to 1 nitrogen and of nitrogen to 100 carbon. For many purposes it is convenient to have all of these expressed side by side. For the consideration and comparison, however, of the quantities of each single constituent, it is more convenient to have the nitrogen and carbon results tabulated separately, in such a way as to show in one line the quantities present in each successive depth of each plat. Tables 13, 14, 15, and 16 exhibit the total nitrogen and organic carbon contents of the soils and subsoils in this separate form:

TABLE 11.—*Broadbalk wheat soils, sampled in October, 1893*—NITROGEN *and* CARBON *in fine dry soil, expressed as percentages and as pounds per acre, also ratio of carbon to nitrogen and of nitrogen to carbon.*

FIRST 9 INCHES.

Plat.	Annual manuring.	Nitrogen per acre in manure.	Total nitrogen.	Nitrogen as nitrates per million.	Carbon.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.	Ratio of— Carbon to 1 nitrogen.	Ratio of— Nitrogen to 100 carbon.
		Lbs.	*Per ct.*	*Parts.*	*Per ct.*	*Lbs.*	*Lbs.*	*Lbs.*		
2a	Farmyard manure since 1884	200	0.1628	9.43	1.582	4,087	23.67	39,711	9.7	10.3
2b	Farmyard manure, 50 years	200	.2207	4.51	2.230	5,151	10.53	52,046	10.1	9.9
3	Unmanured	0	.0992	3.72	.888	2,572	9.64	23,022	9.0	11.2
4	Unmanured since 1852	0	.0982	3.07	.909	2,546	7.96	23,567	9.3	10.8
5	Full minerals	0	.1013	4.06	.931	2,626	10.53	24,137	9.2	10.9
6	Full minerals and ammonium salts	43	.1107	5.45	1.019	2,870	14.13	26,419	9.2	10.9
7	Full minerals and ammonium salts	86	.1222	5.77	1.101	3,168	14.96	28,545	9.0	11.1
8	Full minerals and ammonium salts	129	.1188	6.71	1.138	3,080	17.40	29,504	9.6	10.4
9a	Full minerals and sodium nitrate	43	1189	6.41	1 162	3,083	16.62	30,126	9.8	10.2
9b	Sodium nitrate only	43	.1094	4.28	1.008	2,836	11.10	26,134	9.2	10.9
10a	Ammonium salts (no minerals since '44)	86	.1069	4.83	1.049	2,772	12.52	27,197	9.8	10.2
10b	Ammonium salts (no minerals since '50)	86	.1064	3.64	.969	2,759	9.44	25,122	9.1	11.0
11	Phosphates and ammonium salts	86	.1131	4.50	1.107	2,932	11.67	28,700	9.8	10.2
12	Phosphates, sodium, and ammonium salts	86	.1194	5.46	1.123	3,096	14.16	29,115	9.4	10.6
13	Phosphates, potassium, and ammonium salts	86	.1162	5.37	1.165	3,013	13.92	30,204	10.0	10.0
14	Phosphates, magnesium, and ammonium salts	86	.1250	5.16	1.137	3,241	13.38	29,478	9.1	11.0
15	Full minerals and ammonium salts (autumn)	86	.1234	3.86	1.170	3,199	10.01	30,334	9.5	10.5
16	Full minerals and sodium nitrate since 1884	86	.1177	5.24	1.065	3,052	13.59	27,611	9.0	11.1
17	Full minerals and ammonium salts transposed in alternate years.	86	.1174	4.70	1.094	3,044	12.19	28,363	9.3	10.7
18			.1232	4.49	1.146	3,194	11.64	29,711	9.3	10.8
19	Rape cake	93	.1348	8.55	1.257	3,478	22.06	32,430	9.3	10.7
	Average (excluding 2a and 2b)		.1149	5.01	1.076	2,977	13.00	27,880	9.4	10.7
	Average (all plats)		.1222	5.20	1.155	3,133	13.38	29,594	9.5	10.6

TABLE 11.—*Broadbalk wheat soils, etc.*—Continued.

SECOND 9 INCHES.

Plat.	Annual manuring.	Nitrogen per acre in manure.	Total nitrogen.	Nitrogen as nitrates per million.	Carbon.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.	Ratio of— Carbon to 1 nitrogen.	Ratio of— Nitrogen to 100 carbon.
		Lbs.	*Per ct.*	*Parts.*	*Per ct.*	*Lbs.*	*Lbs.*	*Lbs.*		
2a	....	200	0.0811	8.48	0.645	2,166	22.65	17,230	7.9	12.6
2b	....	200	.0767	16.98	.748	2,049	45.36	19,981	9.7	10.2
3	....	0	.0730	3.45	.565	1,950	9.22	15,093	7.7	12.9
4	....	0	.0783	2.63	.600	2,092	7.03	16,028	7.7	13.0
5	....	0	.0739	2.38	.587	1,974	6.36	15,681	7.9	12.6
6	....	43	.0720	4.77	.583	1,923	12.74	15,574	8.1	12.3
7	....	86	.0681	7.19	.530	1,819	19.21	14,158	7.8	12.8
8	....	129	.0752	10.92	.608	2,009	29.17	16,242	8.1	12.4
9a	....	43	.0849	7.20	.651	2,268	19.23	17,390	7.7	13.0
9b	....	43	.0799	13.05	.640	2,134	34.86	17,096	8.0	12.5
10a	....	86	.0817	9.52	.668	2,182	25.43	17,844	8.2	12.2
10b	....	86	.0820	10.88	.656	2,190	29.06	17,524	8.0	12.5
11	....	86	.0812	9.20	.643	2,169	24.58	17,177	7.9	12.6
12	....	86	.0840	9.54	.643	2,244	25.48	17,177	7.6	13.1
13	....	86	.0757	9.79	.630	2,022	26.15	16,829	8.3	12.0
14	....	86	.0804	11.60	.629	2,148	30.99	16,803	7.8	12.8
15	....	86	.0842	7.00	.727	2,249	18.70	19,421	8.6	11.6
16	....	86	.0783	15.94	.682	2,092	42.58	18,218	8.7	11.5
17	}	86	.0777	10.37	.650	2.076	27.70	17,364	8.4	11.9
18			.0793	15.53	.630	2,118	41.49	16,829	7.9	12.6
19	....	93	.0794	9.12	.719	2,121	24.36	19,307	9.1	11.0
	Average (all plats)	....	.0784	9.31	.640	2,095	24.87	17,093	8.2	12.2

THIRD 9 INCHES.

Plat.	Annual manuring.	Nitrogen per acre in manure.	Total nitrogen.	Nitrogen as nitrates per million.	Carbon.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.	Ratio of— Carbon to 1 nitrogen.	Ratio of— Nitrogen to 100 carbon.
2a	....	200	0.0660	3.68	0.515	1,842	10.27	14,376	7.8	12.8
2b	....	200	.0656	4.39	.492	1,831	12.25	13,734	7.5	13.3
3	....	0	.0651	.98	.483	1,817	2.74	13,483	7.4	13.5
4	....	0	.0644	.76	.463	1,798	2.12	12,925	7.2	13.9
5	....	0	.0645	.80	.446	1,801	2.23	12,450	6.9	14.5
6	....	43	.0628	2.08	.429	1,753	5.81	11,976	6.8	14.6
7	....	86	.0583	3.06	.426	1,627	8.54	11,892	7.3	13.7
8	....	129	.0630	3.12	.443	1,759	8.71	12,366	7.0	14.2
9a	....	43	.0696	2.40	.535	1,943	6.70	14,935	7.7	13.0
9b	....	43	.0690	5.58	.524	1,926	15.58	14,627	7.6	13.2
10a	....	86	.0706	4.03	.526	1,971	11.25	14,683	7.4	13.4
10b	....	86	.0696	5.01	.524	1,943	13.99	14,627	7.5	13.3
11	....	86	.0672	5.33	.492	1,876	14.88	13,734	7.3	13.7
12	....	86	.0733	4.35	.526	2,046	12.14	14,683	7.2	13.9
13	....	86	.0650	3.38	.477	1,814	9.44	13,315	7.3	13.6
14	....	86	.0650	4.22	.502	1,814	11.78	14,013	7.7	12.9
15	....	86	.0693	3.77	.535	1,935	10.52	14,935	7.7	12.9
16	....	86	.0655	7.44	.438	1,828	20.77	12,227	6.7	14.9
17	}	86	.0671	3.06	.492	1,873	8.54	13,734	7.3	13.6
18			.0663	2.29	.478	1,851	6.39	13,343	7.2	13.9
19	....	93	.0719	5.08	.587	2,007	14.18	16,386	8.2	12.2
	Average (all plats)	....	.0666	3.56	.492	1,860	9.94	13,735	7.4	13.5

FOURTH 9 INCHES.

Plat.	Annual manuring.	Nitrogen per acre in manure.	Total nitrogen.	Nitrogen as nitrates per million.	Carbon.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.	Ratio of— Carbon to 1 nitrogen.	Ratio of— Nitrogen to 100 carbon.
5	....	0	0.0524	0.34	0.310	1,459	0.95	8,629	5.9	16.9
6	....	43	.0469	1.07	.263	1,305	2.98	7,321	5.6	17.8
7	....	86	.0466	1.91	.343	1,297	5.32	9,547	7.4	13.6
8	....	129	.0546	3.13	.409	1,520	8.71	11,384	7.5	13.3
11	....	86	.0585	4.19	.371	1,628	11.66	10,327	6.3	15.8
12	....	86	.0634	2.68	.413	1,765	7.46	11,496	6.5	15.3
13	....	86	.0528	1.68	.414	1,470	4.68	11,524	7.8	12.7
14	....	86	.0441	2.46	.329	1,228	6.85	9,158	7.5	13.4
15	....	86	.0441	2.34	.269	1,228	6.51	7,488	6.1	16.4
16	....	86	.0521	4.68	.329	1,450	13.03	9,158	6.3	15.8
17	}	86	.0497	1.03	.307	1,383	2.87	8,545	6.2	16.2
18			.0481	1.21	.315	1,339	3.37	8,768	6.5	15.3
	Average (all plats)	....	.0511	2.23	.339	1,423	6.40	9,445	6.6	15.1

TABLE 11.—*Broadbalk wheat soils, etc.*—Continued.

FIFTH 9 INCHES.

Plat.	Annual manuring.	Nitrogen per acre in manure.	Total nitrogen.	Nitrogen as nitrates per million.	Carbon.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.	Ratio of— Carbon to 1 nitrogen.	Ratio of— Nitrogen to 100 carbon.
		Lbs.	*Per ct.*	*Parts.*	*Per ct.*	*Lbs.*	*Lbs.*	*Lbs.*		
5		0	0.0442	0.35	0.229	1,267	1.00	6,562	5.2	19.3
6		43	.0497	1.21	.250	1,424	3.47	7,164	5.0	19.9
7		86	.0468	1.62	.271	1,341	4.64	7,766	5.8	17.3
8		129	.0497	2.97	.312	1,424	8.51	8,941	6.3	15.9
11		86	.0491	3.00	.304	1,407	8.60	8,711	6.2	16.1
12		86	.0493	2.04	.305	1,413	5.85	8,740	6.2	16.2
13		86	.0517	1.23	.332	1,481	3.52	9,514	6.4	15.6
14		86	.0444	2.13	.278	1,272	6.10	7,966	6.3	16.0
15		86	.0458	1.89	.237	1,312	5.42	6,791	5.2	19.3
16		86	.0543	2.73	.302	1,556	7.82	8,654	5.6	18.0
17		86	.0449	.64	.282	1,287	1.83	8,081	6.3	15.9
18			.0360	1.02	.255	1,032	2.92	7,307	7.1	14.1
	Average (all plats)	......	.0472	1.74	.279	1,351	4.97	8,106	5.9	16.9

SIXTH 9 INCHES.

Plat.	Annual manuring.	Nitrogen per acre in manure.	Total nitrogen.	Nitrogen as nitrates per million.	Carbon.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.	Ratio of— Carbon to 1 nitrogen.	Ratio of— Nitrogen to 100 carbon.
5		0	0.0569	0.25	0.267	1,614	0.71	7,574	4.7	21.3
6		43	.0463	1.31	.244	1,313	3.72	6,922	5.3	19.0
7		86	.0348	1.55	.203	987	4.40	5,759	5.8	17.1
8		129	.0409	2.63	.240	1,160	7.46	6,809	5.9	17.0
11		86	.0404	1.77	.278	1,146	5.02	7,887	6.9	14.5
12		86	.0477	1.78	.298	1,353	5.05	8,454	6.2	16.0
13		86	.0467	1.34	.289	1,325	3.80	8,199	6.2	16.2
14		86	.0438	1.90	.236	1,243	5.39	6,695	5.4	18.6
15		86	.0333	1.52	.197	945	4.31	5,589	5.9	16.9
16		86	.0442	2.10	.294	1,254	5.96	8,340	6.6	15.0
17		86	.0413	.61	.283	1,172	1.73	8,028	6.8	14.6
18			.0397	.58	.240	1,126	1.65	6,809	6.0	16.5
	Average (all plats)	......	.0430	1.44	.256	1,2[illegible]0	4.10	7,255	5.9	16.8

SEVENTH 9 INCHES.

Plat.	Annual manuring.	Nitrogen per acre in manure.	Total nitrogen.	Nitrogen as nitrates per million.	Carbon.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.	Ratio of— Carbon to 1 nitrogen.	Ratio of— Nitrogen to 100 carbon.
5		0	0.0591	0.36	0.269	1,686	1.03	7,673	4.5	22.0
6		43	.0400	1.14	.207	1,141	3.25	5,905	5.2	19.3
7		86	.0416	1.58	.264	1,187	4.51	7,531	6.3	15.8
8		129	.0442	2.80	.249	1,261	7.99	7,103	5.6	17.7
11		86	.0366	1.57	.246	1,044	4.48	7,017	6.7	14.9
12		86	.0423	1.88	.279	1,207	5.36	7,959	6.6	15.2
13		86	.0471	1.24	.297	1,344	3.54	8,472	6.3	15.9
14		86	.0454	1.97	.233	1,295	5.62	6,647	5.1	19.5
15		86	.0353	1.78	.214	1,007	5.08	6,105	6.1	16.5
16		86	.0454	1.91	.270	1,295	5.45	7,702	5.9	16.8
17		86	.0348	.48	.220	993	1.37	6,276	6.3	15.8
18			.0324	.50	.223	924	1.43	6,361	6.9	14.5
	Average (all plats)	....	.0420	1.43	.248	1,199	4.09	7,063	5.9	16.9

EIGHTH 9 INCHES.

Plat.	Annual manuring.	Nitrogen per acre in manure.	Total nitrogen.	Nitrogen as nitrates per million.	Carbon.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.	Ratio of— Carbon to 1 nitrogen.	Ratio of— Nitrogen to 100 carbon.
5		0	0.0568	0.32	0.238	1,629	0.92	6,827	4.2	23.9
6		43	.0322	.66	.192	924	1.89	5,507	6.0	16.8
7		86	.0377	1.40	.176	1,081	4.02	5,048	4.7	21.4
8		129	.0384	2.65	.228	1,101	7.60	6,540	5.9	16.8
11		86	.0371	2.13	.228	1,064	6.11	6,540	6.1	16.3
12		86	.0330	1.85	.257	947	5.31	7,372	7.8	12.8
13		86	.0493	1.24	.255	1,414	3.56	7,314	5.2	19.3
14		86	.0493	2.37	.244	1,414	6.80	6,999	4.9	20.2
15		86	.0303	1.33	.186	869	3.81	5,335	6.1	16.3
16		86	.0479	2.19	.244	1,374	6.28	6,999	5.1	19.6
17		86	.0333	.60	.160	955	1.72	4,589	4.8	20.8
18			.0301	.50	.171	863	1.43	4,905	5.7	17.6
	Average (all plats)	....	.0396	1.44	.215	1,136	4.12	6,165	5.4	18.4

TABLE 11.—*Broadbalk wheat soils, etc.*—Continued.

NINTH 9 INCHES.

Plat.	Annual manuring.	Nitrogen per acre in manure.	Total nitrogen.	Nitrogen as nitrates per million.	Carbon.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.	Ratio of— Carbon to 1 nitrogen.	Ratio of— Nitrogen to 100 carbon.
		Lbs.	*Per ct.*	*Parts.*	*Per ct.*	*Lbs.*	*Lbs.*	*Lbs.*		
5		0	0.0566	0.29	0.225	1,700	0.87	6,758	4.0	25.1
6		43	.0325	.82	.189	976	2.46	5,677	5.8	17.2
7		86	.0355	1.43	.167	1,066	4.29	5,016	4.7	21.3
8		129	.0318	2.04	.174	955	6.13	5,226	5.5	18.3
	Average (all plats)		.0391	1.15	.189	1,174	3.44	5,669	4.8	20.7

TENTH 9 INCHES.

Plat.	Annual manuring.	Nitrogen per acre in manure.	Total nitrogen.	Nitrogen as nitrates per million.	Carbon.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.	Ratio of— Carbon to 1 nitrogen.	Ratio of— Nitrogen to 100 carbon.
5		0	0.0571	0.19	0.258	1,714	0.57	7,745	4.5	22.1
6		43	.0332	.72	.183	997	2.16	5,493	5.5	18.1
7		86	.0332	1.46	.175	997	4.38	5,253	5.3	19.0
8		129	.0265	1.88	.135	795	5.64	4,052	5.1	19.6
	Average (all plats)		.0375	1.06	.188	1,126	3.19	5,636	5.0	20.0

TABLE 12.—*Broadbalk wheat soils sampled in October, 1893*—NITROGEN *and* CARBON *in fine, dry soil as pounds per acre (results condensed and summarized from the extended Table 11).*

FIRST, SECOND, AND THIRD DEPTHS (27 INCHES).

Plat.	Annual manuring.	Per acre. Nitrogen annually in manure.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
2a	Farmyard manure since 1884	200	8,095	56.59	71,317
2b	Farmyard manure 50 years	200	9,031	68.14	85,761
3	Unmanured	0	6,339	21.60	51,598
4	Unmanured since 1852	0	6,436	17.11	52,520
5	Full minerals	0	6,401	19.12	52,268
6	Full minerals and ammonium salts	43	6,546	32.68	53,969
7	do	86	6,614	42.71	54,595
8	do	129	6,848	55.28	58,112
9a	Full minerals and sodium nitrate	43	7,294	42.55	62,451
9b	Sodium nitrate only	43	6,896	61.54	57,857
10a	Ammonium salts (no minerals since 1844)	86	6,925	49.20	59,724
10b	Ammonium salts (no minerals since 1850)	86	6,892	52.49	57,273
11	Phosphates and ammonium salts	86	6,977	51.13	59,611
12	Phosphates, sodium, and ammonium salts	86	7,386	51.78	60,975
13	Phosphates, potassium, and ammonium salts	86	6,849	49.51	60,348
14	Phosphates, magnesium, and ammonium salts	86	7,203	56.15	60,294
15	Full minerals and ammonium salts (autumn)	86	7,383	39.23	64,690
16	Full minerals and sodium nitrate	86	6,972	76.94	58,056
17	Full minerals and ammonium salts, transposed in alternate years.	86	6,993	48.43	59,461
18			7,163	59.52	59,883
19	Rape cake	93	7,606	60.60	68,023

TABLE 12.—*Broadbalk wheat soils, etc.*—Continued.

FIRST TO EIGHTH DEPTHS (72 INCHES).

Plat.	Annual manuring.	Per acre.			
		Nitrogen annually in manure.	Total nitrogen.	Nitrogen as nitrates.	Carbon.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
5	....	0	14,056	23.73	89,533
6	....	43	12,653	47.99	86,788
7	....	86	12,507	65.60	90,246
8	....	129	13,314	95.55	98,889
11	....	86	13,266	87.00	100,093
12	....	86	14,071	80.81	104,996
13	....	86	13,883	68.61	105,371
14	....	86	13,655	86.91	97,759
15	....	86	12,744	64.36	95,998
16	....	86	13,901	115.48	98,909
17	....	86	12,783	57.95	94,980
18			12,447	70.32	94,033

FIRST TO TENTH DEPTHS (90 INCHES).

Plat.	Annual manuring.	Nitrogen annually in manure.	Total nitrogen.	Nitrogen as nitrates.	Carbon.
5	....	0	17,470	25.17	104,036
6	....	43	14,626	52.61	97,958
7	....	86	14,570	74.27	100,515
8	....	129	15,064	107.32	108,167

TABLE 13.—*Broadbalk wheat soils, samples collected October 13 to 21, 1893—Percentages of* TOTAL NITROGEN *in fine dry soil (determined by Kjeldahl method).*

Plat.	Manure per acre per annum.	Nitrogen in manure per acre per annum.	First depth.	Second depth.	Third depth.	Fourth depth.	Fifth depth.	Sixth depth.	Seventh depth.	Eighth depth.	Ninth depth.	Tenth depth.
		Pounds.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
2a	Farmyard manure since 1884	200	0.1628	0.0811	0.0660	......	......	......	......	......	......	......
2b	Farmyard manure 50 years	200	.2207	.0767	.0656	......	......	......	......	......	......	......
3	Unmanured	0	.0992	.0730	.0651	......	......	......	......	......	......	......
4	Unmanured since 1852	0	.0982	.0783	.0644	......	......	......	......	......	......	......
5	Full minerals	0	.1013	.0739	.0645	0.0524	0.0442	0.0569	0.0591	0.0568	0.0566	0.571
6	Full minerals and ammonium salts	43	.1107	.0720	.0628	.0469	.0497	.0463	.0400	.0322	.0325	.332
7	....do	86	.1222	.0681	.0583	.0466	.0468	.0348	.0416	.0377	.0355	.332
8	....do	129	.1188	.0752	.0630	.0546	.0497	.0409	.0442	.0384	.0318	.265
9a	Full minerals and sodium nitrate	43	.1189	.0849	.0696	......	......	......	......	......	......	......
9b	Sodium nitrate only	43	.1094	.0799	.0690	......	......	......	......	......	......	......
10a	Ammonium salts (no minerals since 1844)	86	.1069	.0817	.0706	......	......	......	......	......	......	......
10b	Ammonium salts (no minerals since 1850)	86	.1064	.0820	.0696	......	......	......	......	......	......	......
11	Phosphates and ammonium salts	86	.1131	.0812	.0672	.0585	.0491	.0404	.0366	.0371	......	......
12	Phosphates, sodium, and ammonium salts	86	.1194	.0840	.0733	.0634	.0493	.0477	.0423	.0330	......	......
13	Phosphates, potassium, and ammonium salts	86	.1162	.0757	.0650	.0528	.0517	.0467	.0471	.0493	......	......
14	Phosphates, magnesium, and ammonium salts	86	.1250	.0804	.0650	.0441	.0444	.0438	.0454	.0493	......	......
15	Full minerals and ammonium salts (autumn)	86	.1234	.0842	.0693	.0441	.0458	.0333	.0353	.0303	......	......
16	Full minerals and sodium nitrate since 1884	86	.1177	.0783	.0655	.0521	.0543	.0442	.0454	.0479	......	......
17	Full minerals and ammonium salts transposed in alternate years	*a* 86	.1174	.0777	.0671	.0497	.0449	.0413	.0348	.0333	......	......
18			.1232	.0793	.0663	.0481	.0360	.0397	.0324	.0301	......	......
19	Rape cake	93	.1348	.0794	.0719	......	......	......	......	......	......	......

a Alternate years: Plat 18 received the 86 pounds nitrogen in the form of ammonium salts for the crop of 1893.

TABLE 14.—*Broadbalk wheat soils, samples collected in October, 1893*—TOTAL NITROGEN *in pounds per acre (calculated on determinations made by the Kjeldahl method).*

Plat.	Manure per acre per annum.	Nitrogen in manure per acre per annum.	First 9 inches.	Second 9 inches.	Third 9 inches.	Fourth 9 inches.	Fifth 9 inches.	Sixth 9 inches.	Seventh 9 inches.	Eighth 9 inches.	Ninth 9 inches.	Tenth 9 inches.	Summary. First to third 9 inches.	Summary. First to Eighth 9 inches.	Summary. Ninth and tenth 9 inches.	Summary. First to tenth 9 inches.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
2a	Farmyard manure since 1884	200	4,0[illegible]7	2,166	1,842	...	...	...	...	...	...	...	8,095	...	...	...
2b	Farmyard manure 50 years	200	5,151	2,049	1,831	...	...	...	...	...	...	...	9,031	...	...	...
3	Unmanured	0	2,572	1,950	1,817	...	...	...	...	...	...	...	6,339	...	...	...
4	Unmanured since 1852	0	2,546	2,092	1,798	...	...	...	...	...	...	...	6,436	...	...	...
5	Full minerals	0	2,626	1,974	1,801	1,459	1,267	1,614	1,686	1,629	1,700	1,714	6,401	14,056	3,414	17,470
6	Full minerals and ammonium salts	43	2,870	1,923	1,753	1,305	1,424	1,313	1,141	924	976	997	6,546	12,653	1,973	14,626
7	do	86	3,168	1,819	1,627	1,297	1,341	987	1,18[illegible]	1,081	1,066	997	6,614	12,507	2,063	14,570
8	do	129	3,080	2,009	1,759	1,520	1,424	1,160	1,261	1,101	955	795	6,848	13,314	1,750	15,064
9a	Full minerals and sodium nitrate	43	3,083	2,268	1,943	...	...	...	...	...	...	...	7,294	...	...	...
9b	Sodium nitrate only	43	2,836	2,134	1,926	...	...	...	...	...	...	...	6,896	...	...	...
10a	Ammonium salts (no minerals since 1844)	86	2,772	2,182	1,971	...	...	...	...	...	...	...	6,925	...	...	...
10b	Ammonium salts (no minerals since 1850)	86	2,759	2,190	1,943	...	...	...	...	...	...	...	6,892	...	...	...
11	Phosphates and ammonium salts	86	2,932	2,169	1,876	1,628	1,407	1,146	1,044	1,064	...	...	6,977	13,266	...	...
12	Phosphates, sodium, and ammonium salts	86	3,096	2,244	2,046	1,765	1,413	1,353	1,207	947	...	...	7,386	14,071	...	...
13	Phosphates, potassium, and ammonium salts	86	3,013	2,022	1,814	1,470	1,481	1,325	1,344	1,414	...	...	6,849	13,883	...	...
14	Phosphates, magnesium, and ammonium salts	86	3,241	2,148	1,814	1,228	1,272	1,243	1,295	1,414	...	...	7,203	13,655	...	...
15	Full minerals and ammonium salts (autumn)	86	3,199	2,249	1,935	1,228	1,312	945	1,007	869	...	...	7,383	12,744	...	...
16	Full minerals and sodium nitrate since 1884	86	3,052	2,092	1,828	1,450	1,556	1,254	1,295	1,374	...	...	6,972	13,901	...	...
17	Full minerals and ammonium salts transposed in alternate years	*a* 86	3,044	2,076	1,873	1,383	1,287	1,172	993	955	...	...	6,993	12,783	...	...
18			3,194	2,118	1,851	1,339	1,032	1,126	924	863	...	...	7,163	12,447	...	...
19	Rape cake	93	3,478	2,121	2,007	...	...	...	...	...	...	...	7,606	...	...	...

a Plat 18 received the 86 pounds nitrogen in the form of ammonium salts for the crop of 1893.

TABLE 15.—*Broadbalk wheat soils, samples collected October 13 to 21, 1893—Percentages of* ORGANIC CARBON *in fine dry soil.*

Plat.	Manure per acre per annum.	Nitrogen in manure per acre per annum.	First depth.	Second depth.	Third depth.	Fourth depth.	Fifth depth.	Sixth depth.	Seventh depth.	Eighth depth.	Ninth depth.	Tenth depth.
		Pounds.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
2a	Farmyard manure since 1884	200	1.582	0.645	0.515	....	....	....	....	....	....	....
2b	Farmyard manure 50 years	200	2.230	.748	.492	....	....	....	....	....	....	....
3	Unmanured	0	.888	.565	.483	....	....	....	....	....	....	....
4	Unmanured since 1852	0	.909	.600	.463	....	....	....	....	....	....	....
5	Full minerals	0	.931	.587	.446	0.310	0.229	0.267	0.269	0.238	0.225	0.258
6	Full minerals and ammonium salts	43	1.019	.583	.429	.263	.250	.244	.207	.192	.189	.183
7	....do	86	1.101	.530	.426	.343	.271	.203	.264	.176	.167	.175
8	....do	129	1.138	.608	.443	.409	.312	.240	.249	.228	.174	.135
9a	Full minerals and sodium nitrate	43	1.162	.651	.535	....	....	....	....	....	....	....
9b	Sodium nitrate only	43	1.008	.640	.524	....	....	....	....	....	....	....
10a	Ammonium salts (no minerals since 1844)	86	1.049	.668	.526	....	....	....	....	....	....	....
10b	Ammonium salts (no minerals since 1850)	86	.969	.656	.524	....	....	....	....	....	....	....
11	Phosphates and ammonium salts	86	1.107	.643	.492	.371	.304	.278	.246	.228	....	....
12	Phosphates, sodium, and ammoninm salts	86	1.123	.643	.526	.413	.305	.298	.279	.257	....	....
13	Phosphates, potassium, and ammonium salts	86	1.165	.630	.477	.414	.332	.289	.297	.255	....	....
14	Phosphates, magnesium, and ammonium salts	86	1.137	.629	.502	.329	.278	.236	.233	.244	....	....
15	Full minerals and ammonium salts (autumn)	86	1.170	.727	.535	.269	.237	.197	.214	.186	....	....
16	Full minerals and sodium nitrate since 1884	86	1.065	.682	.438	.329	.302	.294	.270	.244	....	....
17	Full minerals and ammonium salts transposed in alternate years	*a* 86	1.094	.650	.492	.307	.282	.283	.220	.160	....	....
18			1.146	.630	.478	.315	.255	.240	.223	.171	....	....
19	Rape cake	93	1.257	.719	.587	....	....	....	....	....	....	....

a Plat 18 received the 86 pounds nitrogen in the form of ammonium salts for the crop of 1893.

TABLE 16.—*Broadbalk wheat soils, samples collected in October, 1893*—ORGANIC CARBON *in pounds per acre.*

Plat.	Manure per acre per annum.	Nitrogen in manure per acre per annum.	First 9 inches.	Second 9 inches.	Third 9 inches.	Fourth 9 inches.	Fifth 9 inches.	Sixth 9 inches.	Seventh 9 inches.	Eighth 9 inches.	Ninth 9 inches.	Tenth 9 inches.	Summary. First to third 9 inches.	Summary. First to eighth 9 inches.	Summary. Ninth and tenth 9 inches.	Summary. First to tenth 9 inches.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
2a	Farmyard manure since 1884	200	39,711	17,230	14,376								71,317			
2b	Farmyard manure 50 years	200	52,046	19,981	13,734								85,761			
3	Unmanured	0	23,022	15,093	13,483								51,598			
4	Unmanured since 1852	0	23,567	16,028	12,925								52,520			
5	Full minerals	0	24,137	15,681	12,450	8,629	6,562	7,574	7,673	6,827	6,758	7,745	52,268	89,533	14,503	104,036
6	Full minerals and ammonium salts	43	26,419	15,574	11,976	7,321	7,164	6,922	5,905	5,507	5,677	5,493	53,969	86,788	11,170	97,958
7	do	86	28,545	14,158	11,892	9,547	7,766	5,759	7,531	5,048	5,016	5,253	54,595	90,246	10,269	100,515
8	do	129	29,504	16,242	12,366	11,384	8,941	6,809	7,103	6,540	5,226	4,052	58,112	98,889	9,278	108,167
9a	Full minerals and sodium nitrate	43	30,126	17,390	14,935								62,451			
9b	Sodium nitrate only	43	26,134	17,096	14,627								57,857			
10a	Ammonium salts (no minerals since 1844)	86	27,197	17,844	14,683								59,724			
10b	Ammonium salts (no minerals since 1850)	86	25,122	17,524	14,627								57,273			
11	Phosphates and ammonium salts	86	28,700	17,177	13,734	10,327	8,711	7,887	7,017	6,540			59,611	100,093		
12	Phosphates, sodium, and ammonium salts	86	29,115	17,177	14,683	11,496	8,740	8,454	7,959	7,372			60,975	104,996		
13	Phosphates, potassium, and ammonium salts	86	30,204	16,829	13,315	11,524	9,514	8,199	8,472	7,314			60,348	105,371		
14	Phosphates, magnesium, and ammonium salts	86	29,478	16,803	14,013	9,158	7,966	6,695	6,647	6,999			60,294	97,759		
15	Full minerals and ammonium salts (autumn)	86	30,334	19,421	14,935	7,488	6,791	5,589	6,105	5,335			64,690	95,998		
16	Full minerals and sodium nitrate since 1884	86	27,611	18,218	12,227	9,158	8,654	8,340	7,702	6,999			58,056	98,909		
17	Full minerals and ammonium salts transposed in alternate years	*a* 86	28,363	17,364	13,734	8,545	8,081	8,028	6,276	4,589			59,461	94,980		
18			29,711	16,829	13,343	8,768	7,307	6,809	6,361	4,905			59,883	94,033		
19	Rape cake	93	32,430	19,207	16,386								68,023			

a Plat 18 received the 86 pounds nitrogen in the form of ammonium salts for the crop of 1893.

TOTAL NITROGEN IN UNMANURED AND IN CONTINUOUSLY DUNGED PLATS.

The two plats which seem naturally to claim our first attention are the plats which for fifty years have been the most diverse in their treatment, namely, the continuously cropped but wholly unmanured plat (No. 3), with its almost unmanured companion (No. 4) on the one hand, and on the other hand plat 2b, which in the course of the fifty years ended in 1893 had received no less than 700 tons of dung, estimated to have supplied 200 pounds per annum, or in all 10,000 pounds, of nitrogen, the greater part of which would originally exist in an organic condition, and we naturally look at once to see how their nitrogen contents compare. Glancing down the columns of Table 13 we find, as we should expect, that, as regards nitrogen, they are respectively the poorest and the richest of the plats.

We find as follows:

TABLE 17.—*Broadbalk wheat soils (1893), plats 3, 4, and 2b.*

	Nitrogen.	
	Per cent.	Pounds per acre.
Plat 3, continuously unmanured (first 9 inches only)	0.0992	2,572
Plat 4, unmanured since 1852 (first 9 inches only)	.0982	2,546
Plat 2b, 14 tons farmyard manure per annum (first 9 inches only)	.2207	5,151

Plats 3 and 4, then, have less than 0.1 per cent of organic nitrogen, while plat 2b has over 0.22 per cent.

Allowing for the differences of lightness in the soils (see previous discussion), the permanently dunged surface soil contains as nearly as possible twice as much organic nitrogen as the unmanured soil, the excess in round numbers being about 2,500 pounds per acre.

The manured plat has yielded in its crops in fifty years something like 1,600 pounds more of nitrogen per acre than the unmanured plat. Of the total 10,000 pounds of nitrogen estimated to have been supplied, then, we find (in rough, round numbers) that 1,600 pounds have been recovered in the increased crops, and that about 2,500 pounds are found in the surface soil, leaving 5,900 (or, in round numbers, 6,000) pounds to be accounted for otherwise.

In the second 9 inches we find:

TABLE 18.—*Broadbalk wheat soils (1893), plats 3, 4, and 2b (second 9 inches).*

	Nitrogen.	
	Per cent.	Pounds per acre.
Plat 3, continuously unmanured (second 9 inches)	0.0730	1,950
Plat 4, unmanured since 1852 (second 9 inches)	.0783	2,092
Plat 2b, 14 tons farmyard manure per annum (second 9 inches)	.0767	2,049

Obviously there is no such difference here as to account satisfactorily for the disappearance; indeed, the subsoil of one of the unmanured plats is actually richer than that of the manured plat, and if we travel into the third depth we find that all three are practically alike.

Although formidable difficulties are placed in the way of quantitative acreage deductions from the subsoil analyses, owing to the natural irregularities of the subsoil to which I have already alluded, we are nevertheless able at once to draw from the figures a rough deduction that the organic matter supplied to the land in the form of farmyard dung, even if some of it becomes bodily transferred to the subsoil by the agency of worms or insects or by any other means, does not materially affect the permanent nitrogen contents of the subsoil. There seems, from the carbon results, to be some evidence of increase of organic matter in the upper subsoil beyond what is probably attributable to root residue; but, if this is so, it is organic matter so far decomposed that its nitrogen does not seem to have been conserved.

THE TWO DUNGED PLATS (2a AND 2b).

As a further illustration of this we may compare the soils and subsoils of plats 2a and 2b, the former of which had been dunged for only nine years and the latter for fifty years, the nitrogen supply in the former case being estimated at 1,800 pounds only and in the latter case at 10,000 pounds.

TABLE 19.—*Broadbalk wheat soils (1893), plats 2a and 2b.*

	Nitrogen.		Carbon.	
	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
Plat 2a, dunged nine years:				
First 9 inches	0.1628	4,087	1.582	39.711
Second 9 inches	.0811	2,166	.645	17,230
Third 9 inches	.0660	1,842	.515	14,376
Plat 2b, dunged fifty years:				
First 9 inches	.2207	5,151	2.230	52,046
Second 9 inches	.0767	2.049	.748	19,981
Third 9 inches	.0656	1,831	.492	13,734

It is clear, therefore, that, in spite of the notable surface accumulation, but little of the large quantities of nitrogen supplied in dung and not returned in crops is to be found in the subsoil. The greater part of it has disappeared, either as nitrates in the drainage, or perhaps, and probably largely, by fermentative processes yielding free nitrogen. The question of drainage will have to be discussed hereafter; for the moment we are only concerned with the converse question of accumulation.

RAPE-CAKE PLAT.

Next in order to the dunged plats in point of richness in total nitrogen is the only other plat of the series which has been persistently treated with organic nitrogenous manure, viz, plat 19, which constantly receives rape cake, the quantity since 1883 being from 16 to 17 hundredweight per annum, estimated to contain 93 pounds of nitrogen per annum. The crops yielded by this plat have been inferior to those of most of the chemically manured plats receiving inorganic nitrogen (ammonium salts or sodium nitrate) with a liberal supply of minerals. But there has been accumulated a distinctly larger quantity of organic nitrogen; that is to say, there is in the surface soil an accumulation of nitrogen clearly due to the organic matter of the manure, apart from that due to crop residues. We may compare this plat with plat 3 (wholly unmanured), and with the average of plats 7, 11, 12, 13, 14, 15, and 16, all receiving annually nearly as much nitrogen as the rape-cake plat, but in the form of ammonium salts or sodium nitrate, and also receiving phosphates with or without various alkaline salts.

TABLE 20.—*Broadbalk wheat soils, 1893—Comparison of chemically manured plats and Rape-cake plat.*

NITROGEN.

Plat.	Average yield for forty-two years.		Per cent.			Pounds per acre.		
	Wheat.	Straw.	First 9 inches.	Second 9 inches.	Third 9 inches.	First 9 inches.	Second 9 inches.	Third 9 inches.
	Bushels.	*Cwt.*						
Plat 3, unmanured	12¾	10⅝	0.0992	0.0730	0.0651	2,572	1,950	1,817
Average of plats 7, 11, 12, 13, 14, 15, and 16. Minerals with ammonium salts (or sodium nitrate) containing 86 pounds nitrogen per annum	29½	29	.1196	.0788	.0662	3,100	2,106	1,848
Plat 19, rape cake, containing 93 pounds nitrogen per annum	28	25⅝	.1348	.0794	.0719	3,478	2,121	2,007

CARBON.

Plat.	Wheat.	Straw.	First 9 inches.	Second 9 inches.	Third 9 inches.	First 9 inches.	Second 9 inches.	Third 9 inches.
Plat 3, unmanured	12¾	10⅝	0.888	0.565	0.483	23,022	15,093	13,483
Average of plats 7, 11, 12, 13, 14, 15, and 16. Minerals with ammonium salts (or sodium nitrate) containing 86 pounds nitrogen per annum	29½	29	1.124	.641	.485	29,141	17,112	13,685
Plat 19, rape cake, containing 93 pounds nitrogen per annum	28	25⅝	1.257	.719	.587	32,430	19,307	16,385

As more organic matter has been formed above ground, as grain and straw, in the average of the plats receiving ammonium salts, we may suppose that more stubble and root residue has on the average been left by each crop than on the rape-cake plat. The much larger nitrogen accumulation, therefore, in the surface soil of the rape-cake plat must be attributed to the direct accumulation of nitrogenous organic matter from the rape cake itself. Not only does the surface soil contain 900 pounds per acre of nitrogen more than the unmanured plat 3, but it contains nearly 380 pounds more than the average surface soil of the seven plats cited. In the second 9 inches, although plat 19 contains more than the unmanured plat, there is, however, practically no difference between it and the average second 9 inches of the seven plats. In the third depth there is a very decided difference, the rape-cake plat containing more than the others. In both the second and third depths of plat 19 there is a much larger quantity of carbon than in the average corresponding depth of the seven plats, and one is inclined to draw the conclusion that the organic matter of the rape cake, including some of its nitrogenous compounds or organic bodies derived from them, has found its way more deeply down than has the organic matter of the dung. But not too much stress must be laid upon this, for averages are apt sometimes to lead to delusive conclusions, and a study of the subsoil results seems to show a gradation, though not a uniform one, in the subsoils in the nature of an increase of nitrogen as we go across the field, the subsoils of plats 2a to 8 showing less nitrogen than those of plats 9a to 18; and the increase of nitrogen in the third depth of plat 19, as compared with even its neighbor, plat 18, may possibly be at least partly due to natural increase in this roughly graduated irregularity. This natural irregularity in the subsoils is no doubt mainly due to differences in the proportion of nitrogen-bearing clay and of fine gravel or sand with which it is mixed.

THE CHEMICALLY MANURED PLATS.

PLAT 5 (MINERAL MANURES ONLY).

We may now turn to the various chemically manured plats. One of them, plat 5, has received for fifty years a full supply of minerals without nitrogen in any form whatever. As compared with the unmanured plat 3, it has produced a uniformly larger crop of corn and straw, showing an average increase over the unmanured plat, over forty-two years, of 2 bushels of wheat and 1 hundredweight of straw. We might expect it, therefore, to be poorer in nitrogen than the wholly unmanured plat, but this is not the case. Indeed, we find a slight increase, and with it a distinct increase in organic carbon, as shown in Table 21.

TABLE 21.—*Broadbalk wheat soils, 1893—Plat 3 (unmanured) and plat 5 (mineral manures only).*

Depth.	Nitrogen.		Carbon.	
	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
Plat 3, unmanured:				
First 9 inches	0.0992	2,572	0.888	23,022
Second 9 inches	.0730	1,950	.565	15,093
Third 9 inches	.0651	1,817	.483	13,483
Plat 5, minerals only:				
First 9 inches	.1013	2,626	.931	24,137
Second 9 inches	.0739	1,974	.587	15,681
Third 9 inches	.0645	1,801	.446	12,450

Notwithstanding the annual removal in crops of something like 3 pounds more of nitrogen per acre per annum for the last forty years (or probably nearly 5 pounds per annum, if we include in the average the earlier years of the experiments), the surface soil of plat 5 now contains distinctly more nitrogen, and no diminution is indicated in the second and third depths. The organic carbon is also greater in the surface soil of plat 5 to the extent of over 1,100 pounds per acre, and in the second depth to the extent of nearly 600 pounds per acre. The difference is clearly to be attributed to crop residue, and the fact that plat 5 is now richer in nitrogen than plat 3 is due to the storing up in stubble and root residue of a portion of the natural soil nitrogen that without mineral manure to aid in its assimilation would have been lost, as on plat 3, in drainage.

It must not, even for a moment, however, be supposed that plat 5 has gained nitrogen. We shall see hereafter, on comparison of the nitrogen results obtained by the examination of samples collected in 1865 and 1881, that the soils of both plats are steadily losing nitrogen; but the loss on plat 5, owing to the influence of the mineral manure, has been less than on the wholly unmanured plat.

GENERAL COMPARISON OF ALL CHEMICALLY MANURED PLATS.

We may next pass to the perhaps more practically interesting series of plats which, although they receive no dung or other form of organic nitrogen, have nevertheless received nitrogen in the form of ammonium salts or, in some cases, of sodium nitrate, with and without various additions of minerals.

It will be most instructive to concentrate our attention on the surface soil; that is to say, on the first 9 inches. The results of the subsoil analyses are all to be found in the collective tables, where they can at leisure be consulted in detail; but the natural irregularities already several times referred to must be taken into account, and this renders a detailed examination of the subsoil results for each of the many plats, as regards organic nitrogen and carbon, too large a task to be entered upon now.

It will be convenient to give here, for the plats now under consideration, an abstract showing briefly the mode of manuring, the average yield of crops for forty-two years, and the quantities of nitrogen and carbon in the surface soil depths.

The average annual crops are expressed in pounds and are the sum of the average annual weight of grain and straw, the weight of grain being calculated with reference to the average weight per bushel for each separate plat, as recorded in the official "Memoranda."

For a reason that will presently be seen, the plats are here arranged in the order of the annual total yield of grain and straw, plats 3 and 4 (unmanured) and plat 5, already referred to, being included for purposes of comparison.

TABLE 22.—*Broadbalk wheat soils, 1893*—NITROGEN *and* CARBON *in surface soils of various plats, arranged in order of their average total yields of wheat and straw.*

Plat.	Annual manuring.	Nitrogen supplied annually in manure.	Total annual weight of wheat and straw (42 years average).	Nitrogen.		Organic carbon.
				Per cent.	Pounds per acre.	
		Pounds.	*Pounds.*			*Per cent.*
3	Unmanured	0	1,934	0.0992	2,572	0.888
4	Unmanured since 1852	0	2,008	.0982	2,546	.909
5	Mineral manures only	0	2,242	.1013	2,626	.931
10a	Ammonium salts only (400 pounds) (no minerals since 1844)	86	3,104	.1069	2,772	1.049
10b	Ammonium salts only (400 pounds) (no minerals since 1850)	86	3,501	.1064	2,759	.969
9b	Sodium nitrate only: Formerly 550 pounds, containing / Latterly 275 pounds, containing	86 / 43	3,789	.1094	2,836	1.008
6	Full minerals and ammonium salts (200 pounds)	43	3,842	.1107	2,870	1.019
11	Phosphates and ammonium salts (400 pounds)	86	3,988	.1131	2,932	1.107
16	Full minerals and sodium nitrate (550 pounds) since 1884 (previously unmanured for 19 years)	86	4,824	.1177	3,052	1.065
12	Phosphates, sodium and ammonium salts (400 pounds)	86	4,973	.1194	3,096	1.123
14	Phosphates, magnesium and ammonium salts (400 pounds)	86	5,112	.1250	3,241	1.137
15	Full minerals and ammonium salts (400 pounds) (applied in autumn)	86	5,158	.1234	3,199	1.170
13	Phosphates, potassium and ammonium salts) (400 pounds)	86	5,365	.1162	3,013	1.165
7	Full minerals and ammonium salts (400 pounds)	86	5,629	.1222	3,168	1.101
9a	Full minerals and sodium nitrate: Formerly 550 pounds, containing / Latterly 275 pounds, containing	86 / 43	6,366	.1189	3,083	1.162
8	Full minerals and ammonium salts (600 pounds)	129	6,613	.1188	3,080	1.138

Here, then, the plats are arranged in the order of their annual produce in wheat and straw. With but few exceptions, it will be seen that the percentage of nitrogen and—over a large part of the table—of carbon, also, in the surface soil, increases as the produce has been greater. Thus, in round numbers, the unmanured plats, giving about 2,000 pounds of annual produce, contain, in their surface soil, under 0.10 per cent of nitrogen (with carbon 0.9 per cent); the plat with minerals only giving 2,242 pounds of produce, just over 0.10 per cent of nitrogen (with carbon only slightly over 0.9 per cent); and the plats with ammonium salts but without minerals (save for some early dressings prior to 1851), averaging 3,300 pounds of produce, contain 0.106 per cent of nitrogen (with nearly 1 per cent of carbon). The plat with sodium nitrate without minerals has given more produce than that receiving ammonium salts, although latterly the nitrogen supplied has been only half as much. Probably the sodium nitrate has been a better solvent for the minerals of the soil than ammonium salts; at any rate the produce has been nearly 3,800 pounds, and the nitrogen is over 0.109 per cent (with about 1.01 per cent of carbon).

Then we come to the plats getting minerals as well as ammonium salts. Plat 6 gets full minerals (i. e., superphosphate and potassium, sodium and magnesium salts), with only 43 pounds of nitrogen as ammonium salts. This crop has given more produce than that receiving twice the quantity of ammonium salts without minerals, viz, 3,842 pounds. Its nitrogen is over 0.11 per cent (with carbon about 1.02 per cent).

Then follows a series of plats all getting 86 pounds of nitrogen as ammonium salts (or sodium nitrate), and all well supplied with phosphates, with or without additions of alkaline salts. Plat 11 gets, with 86 pounds of nitrogen as ammonium salts, phosphates only. It shows 146 pounds more of annual produce per acre than plat 6, the next above it, and the nitrogen is increased to 0.113 per cent (with carbon nearly 1.11 per cent). Plat 16 now receives 86 pounds only of nitrogen as sodium nitrate, with full minerals. Its average yield, however, is low, because this average includes nineteen years in which the plat was not manured. Previously to this period it was heavily dressed with ammonium salts, and in 1865 was the richest in nitrogen among the chemically manured plats; but during the long interval between 1865 and the next sampling in 1881, its nitrogen became again reduced nearly to the level of that of plat 3. Since 1884, however, it has received nearly 5 hundredweight of nitrate of soda, containing 86 pounds of nitrogen, per annum; and, after ten years of this treatment, we find that, in 1893, although it does not take quite the leading place, it resumes its rank among the plats comparatively rich in nitrogen, for the nitrogen has risen to nearly 0.118 per cent (the carbon being 1.06 per cent). Notwithstanding the period of starvation, the average annual produce all through has been 4,824 pounds, or 836 pounds higher than that of plat 11, which has been continuously supplied with ammonium salts and phosphates. This difference has, no doubt, been due largely to the full supply of minerals, for it has received a full supply of alkaline salts as well as of phosphates.

Next comes a series of seven plats averaging about 5,600 pounds of annual produce, and averaging rather more than 0.12 per cent of nitrogen (with carbon over 1.14 per cent). In this series the percentages of nitrogen are not all in the order of the crop produce. But, in the whole of the sixteen plats in our list, only four break the sequence to which I have already alluded, viz, that the greater the annual yield of crops, the greater is the percentage of nitrogen found in the surface soil. The plats which individually break this rule or sequence are plats 13, 7, 9a, and 8. These plats have all given large yields, mainly owing to the influence of potassium salts. They have yielded in their crops a considerably larger quantity of nitrogen than any of the others; but they do not show more nitrogen in the surface soil.

One is tempted to ask whether the crops well supplied with phosphates and nitrogen have, under the influence of potassium salts (with, in many cases, sodium and magnesium salts as well), had less difficulty in feeding themselves than those of the plats from which potassium salts have been withheld; and whether in consequence their root development has been, in proportion to above-ground growth, less than in the case of the plats less completely manured. Less annual root development would mean less root residue. Or, again, has the increased assimilative power conferred upon the plant by potash caused the above-ground growth to abstract from the roots, before maturity and death, more of the nitrogen taken up by the roots preparatory to utilization for the ultimate plant processes? On the other hand, we must not forget that we are for the moment speaking as though the first 9 inches comprised the whole of the soil ranged over by the roots. The roots of wheat go very deeply down into the subsoil, and under different treatments the depth of root range no doubt varies, and the luxuriance of rootlet development in different layers of the subsoil probably also varies. And unfortunately the irregularities of the subsoil render it difficult to trace and compare quantitatively the accumulations of organic nitrogen in the subsoil. Some of the subsoils show accumulations in the direction in which we should expect to find them, while others do not. Or again, may it be that the denser and more vigorous growth of the wheat has allowed less growth of weeds on the more richly yielding plats—weeds being, however evil their habits, at least conservators of the nitrogen that they steal? There is yet another view of the matter which is not new, but which should be taken into account, and which has been referred to in earlier communications from Rothamsted. It is that the accumulation of nitrogen under varying circumstances has its varying but necessary limitations—points of increase at which an equilibrium tends to establish itself. Such equilibrium is reached when the annual decomposition of root residue and the final resolution of its nitrogen into the form of nitrates, and consequent annual drainage loss, equals the annual accumulation in root residues. It has, indeed, been previously pointed out to you by Professor Warington that as these decompositions are the work of armies of living organisms, which must increase as their pabulum increases, the very accumulation of root residue furnishes an indirect means for its own increased destruction. It is therefore possible that the somewhat decreased percentage of nitrogen on the most productive plats as compared with those of plats somewhat less productive may be due to some such reaction of natural agencies working toward the establishment of the final equilibrium which we must expect to be inevitably reached under any constant form of treatment.

Perhaps, however, one is led to refine too much, and it may be that the general harmony that otherwise prevails in this table of results leads one to exaggerate the extent or significance of the, after all, slight deviations of these plats from the rule to which, in a broad sense, they may still be said to conform, viz, that the greater the annual crop, and therefore the greater the quantity of nitrogen removed in it from the soil, the greater is the quantity of nitrogen stored in the soil by accumulated crop residues, and so saved from loss in drainage.

PLATS 5 TO 8 (ALL FULLY SUPPLIED WITH MINERAL MANURES, BUT RECEIVING DIFFERENT DRESSINGS OF AMMONIUM SALTS).

This becomes still clearer if, instead of regarding the whole series of chemically manured plats, differing so much both in mineral and in nitrogenous treatment, we select for consideration certain of them which, owing to their comparative treatment, are very strictly comparable. Let us, for instance, tabulate plats 5 to 8, all of which receive annually the same full dressing of minerals (superphosphate, with potassium, sodium, and magnesium salts), but are very differently treated nitrogenously.

TABLE 23.—*Broadbalk wheat soils, 1893—Plats 5, 6, 7, and 8, all annually manured with a liberal supply of superphosphate and of potassium, sodium. and magnesium salts.*

[First 9 inches only.]

	Nitrogen per acre added annually in ammonium salts.	Annual total weight of grain and straw (42 years' average).	Nitrogen.	Carbon.	Excess of crop per acre as compared with plat 5.	Excess of nitrogen per acre in first 9 inches as compared with plat 5.	Excess of carbon per acre in first 9 inches as compared with plat 5.
	Pounds.	*Pounds.*	*Per cent.*	*Per cent.*	*Pounds.*	*Pounds.*	*Pounds.*
Plat 5	....	2,242	0.1013	0.931	....	....	....
Plat 6	43	3,842	.1107	1.019	1,600	244	2,282
Plat 7	86	5,629	.1222	1.101	3,387	542	4,408
Plat 8	129	6,613	.1188	1.138	4,371	454	5,367

In the presence of a full supply of minerals it will be seen that there was a progressive increase in crop with a gradual increase of the ammonium salts. The annual application of 86 pounds of nitrogen in the form of ammonium salts gives about double the increase obtained by the use of 43 pounds. A further increase of ammonium salts produces a still greater crop, but the gain is no longer proportional. In fact, speaking generally, season by season it is noticed at Rothamsted that in the presence of a full supply of minerals the first 43 pounds of nitrogen (as ammonium salts) produces 9 bushels of wheat; the second 43 pounds produces 9 bushels more, making 18 bushels of wheat for 86 pounds of nitrogen; but the third 43 pounds, making a supply of 129 pounds, produces a further increase of only 3 bushels of wheat, and the crop, it may be observed, is usually overgrown and "laid."

It will be seen that the increase in accumulation of nitrogen in the surface soil in plats 6 and 7 (receiving respectively 43 pounds and 86 pounds of nitrogen per acre per annum) as compared with plat 5 (without nitrogen) is respectively 244 pounds and 542 pounds, corresponding very nearly to the doubling of the annual increase in the crop.

On plat 8, where a still larger quantity of ammonium salts is used, and where the increase of crop is much less, there does not appear to be any further accumulation of nitrogen as far as the first 9 inches are concerned.

If, however, we take the second and third depths into account, we certainly find considerably larger accumulations in plat 8 than in plat 7. Indeed, the proportion between the excess of crop and the excess of nitrogen accumulated in the case of plat 8 agrees more nearly with that of plat 5 than does the proportion in the case of plat 7. The following further table shows the results found in 27 inches of soil:

TABLE 24.—*Broadbalk wheat soils, 1893—Plats 6, 7, and 8 further compared.*

[First 27 inches.]

	Nitrogen per acre added annually in ammonium salts.	Excess of crop per acre as compared with plat 5.	Excess of nitogen per acre in first 27 inches as compared with plat 5.	Excess of carbon per acre in first 27 inches as compared with plat 5.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
Plat 6	43	1,600	145	1,701
Plat 7	86	3,387	213	2,327
Plat 8	129	4,371	445	5,844

Whether we take the first 9 inches only or the first 27 inches, the increase in organic carbon is greater as the supply of nitrogen and the growth of crops have been greater, though not in direct proportion, the low percentage of carbon in the samples representing the second and third depths of plat 7 disturbing an otherwise reasonably close concordance in the proportion of crop increase and of increase in residual carbon. But once again it must be remembered that the subsoil irregularities prevent a too close reasoning upon the figures yielded by their analyses for total nitrogen and total carbon.

In fact, the irregularities of the subsoils leave us unable, from direct evidence, to decide whether or not the natural subsoil nitrogen either diminishes by contributing to plant food on the one hand, or is augmented by crop residue on the other, so far as the continuously cropped wheat land is concerned.

PLATS 10a, 11, 13, AND 7 (ALL RECEIVING LIKE DRESSINGS OF AMMONIUM SALTS, BUT DIFFERING IN MINERAL TREATMENT).

Before passing on, I must, at the risk of being tedious, direct specific attention to yet another combination of plats, viz, 10a, 11, 13, and 7. The members of the series we have just been discussing were all alike in being fully manured with phosphates and potassium, sodium, and magnesium salts, differing only in their nitrogenous treatment. Now, the following plats are alike in that they have all for fifty years received ammonium salts containing the same quantity of nitrogen, viz, 86 pounds per acre, but their mineral treatment has varied.

TABLE 25.—*Broadbalk wheat soils, 1893—Plats 10a, 11, 13, and 7, all annually manured with ammonium salts containing 86 pounds nitrogen per acre.*

	Mineral manure.	Total annual weight of wheat and straw (42 years' average).	First 9 inches only.		Annual excess of crop per acre, as compared with plat 10a.	Excess of nitrogen per acre in first 9 inches, as compared with plat 10a.	Excess of carbon per acre in first 9 inches, as compared with plat 10a.
			Nitrogen.	Carbon.			
		Pounds.	*Per ct.*	*Per ct.*	*Pounds.*	*Pounds.*	*Pounds.*
Plat 10a	None	3,104	0.1069	1.049			
Plat 11	Superphosphate	3,988	.1131	1.107	884	160	1,503
Plat 13	Superphosphate and potassium salts.	5,365	.1162	1.165	2,261	241	3,007
Plat 7	Superphosphate and potassium, sodium, and magnesium salts.	5,629	.1222	1.101	2,525	396	1,348

Here again we see that, as the crop has increased on the minerally manured plats, under the influence of more complete feeding, so has the excess of nitrogen in the surface soil increased again in proper sequence, though not in direct proportion.

NITROGEN ACCUMULATIONS AS CROP RESIDUE.

Now a study of the previous series (5, 6, 7, and 8) led clearly to the conclusion that the increase in soil nitrogen followed increased crop, increased crop following an increase of nitrogen applied as ammonium salts, provided that plenty of minerals were also applied. But from those plats alone—save perhaps from the carbon results—we could not draw any valid conclusion as to whether the excess was really rescued nitrogen existing as crop residue or whether it was actually an accumulation of manure. The series 10a, 11, 13, and 7, however, now considered, forms a complement to the other series, showing that even when the application of nitrogen is constant, the smaller the crop the less of it is retained in the soil. The more completely, by the supply of minerals, the crops have been enabled to utilize the nitrogen supplied, the more have they accumulated in the soil; and conversely, the less that is utilized the less is retained.

That whatever storage of manurial nitrogen from inorganic sources (such as ammonium salts or sodium nitrate) takes place in the soil, occurs in the form of crop residues—that is to say, as the remains of roots, stubble, and the débris of weeds—broken down and modified by the influence of the worms, insects, fungi, and bacteria that feed upon them, is not a new conclusion. It was arrived at long since at Rothamsted, and has been largely supported by the study of the composition of the drainage waters from the pipe drains of the wheat plats, as well as by the results of earlier analyses of the soil; and the case is very clearly argued in a Rothamsted paper "On the amount and composition of the rain and drainage waters collected at Rothamsted" (Lawes, Gilbert, and Warington), published in 1881 and 1882,[1] more particularly in that part of the article published in 1882. The matter was also discussed with you, and illustrated from earlier analyses by Professor Warington in his lectures in 1891, and again in a different form, but with a like purport, by Sir Henry Gilbert in his lectures to you in 1893. Although the matter has been already so fully discussed, it has been to me, and I hope may be to you, an interesting task to examine some of the further evidence on the subject yielded by these latest and most interesting analyses, viz, those of the 1893 samples to which we have so far been confining our attention.

LOSS OF NITROGEN.

The following table (Table 26), prepared on the lines of others used in the earlier discussions of the subject, shows at a glance the estimated annual removal of nitrogen in crops in fifty years, and the average annual accumulation of nitrogen in the surface soil, as compared with plat 3, calculated from the present excess found by actual analysis of the 1893 samples. It also shows the nitrogen annually supplied in manure, and the balance annually lost by drainage, or at any rate not found in the surface soil.

TABLE 26.—*Broadbalk wheat soils, sampled in October, 1893*—NITROGEN *in manure, crops, and soil, and not accounted for, on various chemically manured plats.*

Nitrogen.	Plat 3.	Plat 5.	Plat 7.	Plat 10a.	Plat 10b.	Plat 11.	Plat 12.	Plat 13.	Flat 14.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Approximate average annual yield in crops over 50 years *a*	19	24	49	32	35	39	41	45	44
Average annual yield in excess of plat 3 (unmanured)	......	5	30	13	16	20	22	26	25
Average annual accumulation of nitrogen in the surface (first 9 inches) soil, as compared with plat 3 (i. e., one-fiftieth of the excess over plat 3 found by analysis after 50 years)	......	1	12	4	4	7	10½	9	13½
Total annual excess over plat 3 in crops and in first 9 inches of soil	......	6	42	17	20	27	32½	35	38½
Nitrogen supplied annually in manure	......	......	86	86	86	86	86	86	86
Balance annually (on the average) not accounted for in crops or soil—increase in first 9 inches, and for the most part lost by drainage	......	*b* 6	44	69	66	59	53½	51	47½

a This quantity is based on actual analyses of the produce over forty years, and on an estimate (made from the crop yield of each plat) for the earlier years in which analyses of the grain and straw were not made. The average annual estimates, though rough, are probably correct within about 1 pound per acre.
b Gain.

Actual analyses of the drainage waters running from the pipes show quantities of nitrates which go far toward accounting for the lost

[1] Journal of the Royal Agricultural Society of England, 2. ser., 17 (1881), pp. 241–279; 18 (1882), pp. 1–71.

nitrogen, but the drainpipes only discharge a fraction of the total drainage, and a large quantity of drainage must often find its way downward below the level of the drainpipes when the pipes are not running, and even when they are.

Most, if not all, of the loss on the chemically manured plats may therefore be said to be in the form of nitrates. It is possible that under certain conditions of weather there may be slight loss by evolution of free nitrogen from the crop residues of the surface soil on these plats, but there is no evidence to show that any of the nitrogen added in the form of chemical manures is thus lost. But fermentative decomposition involving evolution of free nitrogen no doubt takes place on the heavily and continuously dunged plats, with their high quantity of organic matter, and in a less degree on the rape-cake plat. It is to be borne in mind, however, that the quantity of dung used in these continuous wheat-growing experiments is, on the yearly average, far less than would be used in practical agriculture on any of the rotation systems.

NITROGEN AND CARBON IN THE SUBSOILS.

And now I would for a brief space divert your attention to the subsoil nitrogen rather than to the surface nitrogen.

We have seen that it is not clear that even the higher subsoil has either contributed nitrogen to the crops or has accumulated nitrogen from crop residues, i. e., from the indirect effects of manures; nor, indeed, is it clear how far the subsoil has contributed nitrogen to the nitrates found in or passing through the subsoils, though we have, as we shall see hereafter, some evidence that active nitrification, at any rate, does not occur in the lower subsoil. This statement as to the absence of evidence of accumulation from crop residues, however, must be restricted as referring to evidence of accumulation during the experimental period of fifty years during which the soil has been under continuous wheat cultivation. The diminution of nitrogen from the surface as we go downward into the subsoil is, however, for a certain range gradual and clearly points to accumulations in the past.

It is convenient to consult here a summary table that has been prepared from Table 11 so as to show the nitrogen, carbon, etc., in the average of all the Broadbalk soils at each depth.

TABLE 27.—*Broadbalk wheat soils, sampled in October, 1893*—NITROGEN *and* CARBON *in fine dry soil, showing averages for all plats at different depths.*

[Extracted from Table 11.]

Depth.	Number of plats.	Total nitrogen.	Nitrogen as nitrates.	Carbon.	Per acre. Total nitrogen.	Per acre. Nitrogen as nitrates.	Per acre. Carbon.	Ratio of— Carbon to 1 nitrogen.	Ratio of— Nitrogen to 100 carbon.
		Per cent.	*Per million.*	*Per cent.*	*Lbs.*	*Lbs.*	*Lbs.*		
First 9 inches (excluding 2a and 2b)	19	0.1149	5.01	1.076	2,977	13.00	27,880	9.4	10.7
First 9 inches (all plats)	21	.1222	5.20	1.155	3,133	13.38	29,594	9.5	10.6
Second 9 inches	21	.0784	9.31	.640	2,095	24.87	17,093	8.2	12.2
Third 9 inches	21	.0666	3.56	.492	1,860	9.94	13,735	7.4	13.5
Fourth 9 inches	12	.0511	2.23	.339	1,423	6.40	9,445	6.6	15.1
Fifth 9 inches	12	.0472	1.74	.279	1,351	4.97	8,106	5.9	16.9
Sixth 9 inches	12	.0430	1.44	.256	1,220	4.10	7,255	5.9	16.8
Seventh 9 inches	12	.0420	1.43	.248	1,199	4.09	7,063	5.9	16.9
Eighth 9 inches	12	.0396	1.44	.215	1,136	4.12	6,195	5.4	18.4
Ninth 9 inches	4	.0391	1.15	.189	1,174	3.44	5,669	4.8	20.7
Tenth 9 inches	4	.0375	1.06	.188	1,126	3.19	5,636	5.0	20.0
First 27 inches (excluding 2a and 2b)	19	......	......	......	6,932	47.80	58,520	......	......
First 27 inches (all plats)	21	......	......	......	7,088	48.20	60,420	......	......
First 72 inches	12	......	......	......	13,273	72.02	96,466	......	......
First 90 inches	4	......	......	......	15,432	64.84	102,669	......	......

It will be seen that there is, on the average, a higher percentage of nitrogen in the higher than in the lower layers of the subsoil. This is clear down to the fifth or sixth depth, below which the range is distinctly lower. The individual plats may be studied in detail in Table 11, and it may be said that when in any case the percentage is materially below about 0.04 to 0.045, notes taken at the time of collection of the samples generally show that there was in them a higher proportion of sand or gravel with the clay, or even, at the lower depths, some chalk. The indication seems to be that the higher percentages of nitrogen from the upper soil down to the fifth or sixth depth, i. e., roughly to about 4 feet, may be attributed to gradual distribution downward through centuries of surface supplies or accumulations, in the collection of which leguminous vegetation has no doubt played its part, and when a natural permanent turf also helped to conserve the small annual contributions of nitric nitrogen from the rain and atmosphere, and to minimize the loss of nitrates by natural drainage.

CARBON AND RATIO OF CARBON TO NITROGEN.

It is at this point interesting to consider the results showing the percentage and quantity per acre of carbon in the soils and subsoils. They may be studied in detail in the full statement contained in Table 11, but space may not here be devoted to a full consideration of each plat. Generally speaking, the carbon in the upper subsoil is closely related to the nitrogen, and its fluctuations, like those of the nitrogen, in the upper depths are to be attributed to comparatively recent crop residues. In the surface soil the ratios of carbon to nitrogen vary only from 9:1 to 10:1; but if two plats be excluded (2b and 13) the ratio varies only from 9:1 to 9.8:1, the average being 9.4:1. The actual percentage of carbon varies from 0.888 on plat 3 (unmanured) to 2.230 on plat 2b (permanently dunged). Excluding the dunged plats, it averages 1.076 per cent, or 27,800 pounds of carbon per acre.

In the second depth the variations in carbon on all the plats lie between 0.530 per cent and 0.748 per cent, the latter representing the dunged plat. Excluding this, the range is from 0.530 to 0.727, and the average is 0.640 per cent, or 17,093 pounds per acre. The ratio of carbon to nitrogen ranges from 7.6:1 to 9.7:1, but if two plats (viz, the dunged and rape-cake plats) be excluded, the range is from 7.6:1 to 8.7:1, averaging 8.2:1.

In the third depth the percentage of carbon shows a range of from 0.426 to 0.587 (or from 0.426 to 0.535 if we exclude the rape-cake plat), and averages 0.492 per cent, or 13,735 pounds per acre. The ratio of carbon to nitrogen ranges from 6.7:1 to 8.2:1 (or to 7.8:1 if we exclude the rape-cake plat), the average ratio being 7.4:1.

In the fourth 9 inches we find a range of carbon from 0.263 per cent to 0.414 per cent, with an average of 0.339 per cent, or 9,445 pounds per acre. The ratio of carbon to nitrogen varies from 5.6:1 to 7.8:1, and averages 6.6:1.

In the fifth 9 inches the carbon drops still lower, ranging from 0.229 per cent to 0.332 per cent, and averages only 0.279 per cent, or 8,106 pounds per acre. The ratio of carbon to nitrogen varies from 5.0:1 to 7.1:1, and averages 5.9:1.

In the sixth, seventh, and eighth depths the individual variations are smaller, save from irregularities of sand, etc., such as have been mentioned. The percentages of carbon fall but very gradually, averaging 0.256, 0.248, and 0.215 (from 7,255 to 6,165 pounds per acre). The average carbon to nitrogen ratios are 5.9:1 in both the sixth and seventh depths, and 5.4:1 in the eighth.

In the ninth and tenth depths (4 plats only), the quantities of carbon average only 0.189 per cent and 0.188 per cent, or 5,669 and 5,636 pounds per acre; but one plat shows in these two depths as much as 0.225 per cent and 0.258 per cent (or 6,758 and 7,745 pounds, respectively, per acre).

The table (Table 27) already given shows all the averages at one glance, and shows well the diminution of the ratio of carbon to nitrogen and the converse increase in the ratio of nitrogen to carbon.

The depth at which the carbon ceases to show any marked diminution coincides with the depth at which the nitrogen ceases to diminish much, viz, at the fifth to sixth depth. There also the ratio of carbon to nitrogen, which has been rapidly dwindling from the surface downward, suddenly ceases to diminish. It seems that we at this point come to the depth at which the nitrogen and carbon are little influenced by past surface accumulations or crop residues, and get only, or mainly, the nitrogen and carbon naturally indigenous to the clay itself.

NITROGEN CONTENTS OF VARIOUS OTHER ROTHAMSTED SUBSOILS.

With regard to the question of subsoil as compared with surface nitrogen, it is here relevant to ask how the Broadbalk wheat field compares with other fields and clays from other sources. By the kindness of Sir Henry Gilbert, who has spent much time in their consideration and tabulation, I am able to present here the averages of a very large number of nitrogen determinations in different depths of different fields at Rothamsted. Indeed, the results represent 1,810 different samples taken in various places from the different plats, the nitrogen determinations being for the most part made on a mixture of the samples representing each plat sampled at each depth and at each date of collection. The results, however, are derived from 1,849 separate nitrogen determinations. As the results on all the earlier samples were obtained by the soda-lime method, the soda-lime results for the 1893 wheat soils are in this case taken for comparison.

We have results for the following series of samples:

Broadbalk wheat field.—Samples collected in 1865, 1881, 1887, and 1893.

Hoos field.—Samples collected in 1881 from wheat and clover land; in 1882, 1883, and 1885 from leguminous land and wheat fallow, and in 1868 and 1882 from the barley plats.

Agdell field.—Samples collected from rotation plats in 1867, 1874, and 1883–84.

Barn field.—Various samples collected in 1870 from root land.

In a great number of cases the sampling has been carried down to twelve depths or 9 feet. Tables 28 and 29 show not only the percentages of nitrogen in the fine dry soil, but also the quantities of fine dry soil and stones per acre. The various series of samples are recorded separately in the large table (Table 28), while in the smaller table (Table 29) they are condensed so as to give only the averages of the various series for each of the four fields, but showing also the mean results for the whole 17 sets of samples.

TABLE 28.—*Average weight of fine dry soil and of stones, per acre, in different experimental fields at Rothamsted, and at different depths; also average percentages of nitrogen in the fine dry soils at the respective depths.*

[Summary for each date of collection in each field—Broadbalk, Hoos, Agdell, and Barn fields.]

AVERAGE WEIGHTS OF FINE DRY SOIL PER ACRE.

	First 9 inches.	Second 9 inches.	Third 9 inches.	Fourth 9 inches.	Fifth 9 inches.	Sixth 9 inches.	Seventh 9 inches.	Eighth 9 inches.	Ninth 9 inches.	Tenth 9 inches.	Eleventh 9 inches.	Twelfth 9 inches.
BROADBALK FIELD.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Collected October, 1865 (mean of plats 5, 7, 11, 12, 13, 14, and 16)	2.296,200	2,679,893	2,847,295	----------	----------	----------	----------	----------	----------	----------	----------	----------
Collected October, 1881 (mean of plats 5, 6, 7, 8, 11, 12, 13, 14, 15, 16, 17, and 18)	2,515,902	2,673,368	2,713,300	----------	----------	----------	----------	----------	----------	----------	----------	----------
Collected May, 1887 (mean of plats O, 21, and 22)	2,809,016	2,498,399	2,967,506	2,988,992	2,969,812	3,074,196	2,882,905	2.909.270	2,874,256	2,734,481	2,804,970	2,795,772
Collected October, 1893 (first to eighth mean of plats 5, 6, 7, 8, 11, 12, 13, 14, 15, 16, 17, and 18, ninth and tenth mean of 5, 6, 7, and 8)	2,614,648	2,517,376	2,731,862	2,783,685	2,865,549	2,836,890	2,746,319	2,868,308	3,003,479	3,001,755	----------	----------
Average	2,558.942	2,592,259	2,814,991	2,886,339	2,917,681	2,955,543	2,814,612	2,888,789	2,938.868	2,868,118	2.804,970	2,795,772
HOOS FIELD.												
Collected March, 1881:												
Mean of series 1, plats 2 to 6, clover land	2,732,816	2,720,720	2,879,455	----------	----------	----------	----------	----------	----------	----------	----------	----------
Plat O, 5 holes, wheat land	2,801,640	2,915,473	3,110,355	----------	----------	----------	----------	----------	----------	----------	----------	----------
Collected July, 1882 (*Melilotus leucantha* S1, plats 5 and 6; *Trifolium repens* S1, plat 6)	2,619,433	2,609,621	2,885,387	3,069,382	3,041,889	2,969,839	----------	----------	----------	----------	----------	----------
Collected July, 1883:												
Vicia sativa S1, plats 4 and 6; *Trifolium repens* S1, plat 4	2,688,455	2,599,186	2,678,989	2,866,835	2,951,159	2,925,137	2,871,335	2,896,219	2,752,883	2,498,988	2,411,965	2.570,045
Fallow wheat, plat O	2,616,024	2,990,878	3,218,585	3,234,339	3,277,147	3,231,633	3,159,505	3,094,410	3,177,285	3,109,062	2,853,781	2,992.810
Collected July and August, 1885:												
Melilotus leucantha, *Medicago sativa*, and *Trifolium repens*, each S1, plat 5	2,552,679	2,677,618	2,872,509	2,952,976	2,974,503	2,761,845	2,877,888	2,770,807	2,755,481	2,615,174	2.569,536	2.613,262
Fallow wheat, plat O	2,587,634	2,902,682	3,002,095	3,116,163	3,128,116	3,173,038	3,155,699	3,049,079	3,011,092	3,237,936	3.206,539	3.095,555
Collected March, 1868 (barley 4O, 4A, 4AA, and 4C)	2,276,437	2,546,061	2,684,170	----------	----------	----------	----------	----------	----------	----------	----------	----------
Collected February and March, 1882 (barley; mean of plats 2 and 4, O, A, AA, AAS, and C)	2,464,490	2,523,662	2,684,101	----------	----------	----------	----------	----------	----------	----------	----------	----------
Average	2,593,290	2,720,656	2,890,627	3,047,939	3,074.563	3,012,298	3,016,107	2,952,629	2,924,185	2,865,290	2,760,455	2,817,918

AGDELL FIELD.												
Collected November, 1867 (mean of all 12 plats, after wheat)	2,139,857	2,508,319	2,574,334	....	....	....	....	....	....	....	....	....
Collected October, 1874 (mean of all 12 plats, after clover)	2,399,299	2,437,907	2,551,660	....	....	....	....	....	....	....	....	....
Collected November, 1883, to January, 1884 (mean of all 12 plats, after wheat)	2,503,585	2,398,971	2,472,116	2,441,895	2,465,262	2,587,276	2,517,401	2,654,461	2,589,332	2,478,854	2,610,067	2,644,314
Average	2,347,580	2,448,399	2,532,703	2,441,895	2,465,262	2,587,276	2,517,401	2,654,461	2,589,332	2,478,854	2,610,067	2,644,314
BARN FIELD.												
Collected April, 1870 (mean of plats 4, 5, 6, and 7O, N, A, AC, and C, root land)	2,321,160	2,673,095	2,650,950	....	....	....	....	....	....	....	....	....

AVERAGE WEIGHTS OF TOTAL STONES PER ACRE.

BROADBALK FIELD.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Collected October, 1865 (mean of plats 5, 7, 11, 12, 13, 14, and 16)	531,082	422,960	256,304	....	....	....	....	....	....	....	....	....
Collected October, 1881 (mean of plats 5, 6, 7, 8, 11, 12, 13, 14, 15, 16, 17, and 18)	548,004	364,288	234,683	....	....	....	....	....	....	....	....	....
Collected May, 1887 (mean of plats O, 21, and 22)	409,174	615,851	111,659	99,044	218,308	50,276	265,825	181,210	222,302	176,944	137,359	176,109
Collected October, 1893 (first to eighth mean of plats 5, 6, 7, 8, 11, 12, 13, 14, 15, 16, 17, and 18, ninth and tenth means of 5, 6, 7, and 8)	503,436	372,188	247,974	228,690	186,492	237,765	298,341	239,920	102,955	190,915	....	....
Average	497,924	443,322	212,655	163,867	202,400	144,021	282,083	210,565	162,629	183,930	137,359	176,109
HOOS FIELD.												
Collected March, 1881:												
Mean of series 1, plats 2 to 6, clover land	439,816	246,580	141,675	....	....	....	....	....	....	....	....	....
Plat O, 5 holes, wheat land	376,386	228,956	212,879	....	....	....	....	....	....	....	....	....
Collected July, 1882 (*Melilotus leucantha* S1, plats 5 and 6; *Trifolium repens* S1, plat 6)	507,352	498,489	345,361	181,440	217,807	324,410	....	....	....	....	....	....
Collected July, 1883:												
Vicia sativa S1, plats 4 and 6; *Trifolium repens* S1, plat 4	430,609	343,943	276,334	206,002	178,959	155,092	130,499	184,404	219,615	470,358	445,855	274,065
Fallow wheat, plat O	414,501	200,104	67,382	77,129	57,853	76,230	138,847	194,659	160,628	68,053	293,350	227,329

TABLE 28.—*Average weight of fine dry soil and of stones, per acre, in different experimental fields at Rothamsted, etc.*—Continued.

AVERAGE WEIGHTS OF TOTAL STONES PER ACRE—Continued.

	First 9 inches.	Second 9 inches.	Third 9 inches.	Fourth 9 inches.	Fifth 9 inches.	Sixth 9 inches.	Seventh 9 inches.	Eighth 9 inches.	Ninth 9 inches.	Tenth 9 inches.	Eleventh 9 inches.	Twelfth 9 inches.
HOOS FIELD—continued.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Collected July and August, 1885: *Melilotus leucantha*, *Medicago sativa*, and *Trifolium repens*, each S1, plat 5	391,659	212,519	115,017	190,230	172,734	291,126	160,827	106,468	71,874	235,224	217,201	200,612
Fallow wheat, plat O	340,656	141,861	213,190	197,400	196,819	104,653	26,862	81,675	265,353	65,050	38,659	117,612
Collected March, 1868 (barley 4O, 4A, 4AA, and 4C	719,337	723,768	443,968	.....	.....	.....	.....	.....	.....	.....	.....	.....
Collected February and March, 1882 (barley; mean of plats 2 and 4, O, A, AA, AAS, and C)	705,446	518,857	328,391	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average	480,640	346,120	238,244	170,440	164,834	190,302	114,259	141,802	179,368	209,674	248,766	204,935
AGDELL FIELD.												
Collected November, 1867 (mean of all 12 plats, after wheat)	768,159	447,934	308,549	.....	.....	.....	.....	.....	.....	.....	.....	.....
Collected October, 1874 (mean of all 12 plats, after clover)	939,588	641,126	458,129	.....	.....	.....	.....	.....	.....	.....	.....	.....
Collected November, 1883, to January, 1884 (mean of all 12 plats, after wheat)	781,199	351,339	322,435	476,574	523,083	289,447	472,762	404,655	462,734	528,891	397,621	274,700
Average	837,352	480,133	363,038	476,574	523,083	289,447	472,762	404,655	462,734	528,891	397,621	274,700
BARN FIELD.												
Collected April, 1870 (mean of plats 4, 5, 6, and 7O, N, A, AC, and C, root land)	769,486	530,003	415,488	.....	.....	.....	.....	.....	.....	.....	.....	.....

AVERAGE NITROGEN [1] IN FINE DRY SOIL.

BROADBALK FIELD.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Collected October, 1865 (mean of plats 5, 7, 11, 12, 13, 14, and 16)	0.1199	0.0752	0.0615	.....	.....	.....	.....	.....	.....	.....	.....	.....
Collected October, 1881 (mean of plats 5, 6, 7, 8, 11, 12, 13, 14, 15, 16, 17, and 18)	.1136	.0707	.0596	.....	.....	.....	.....	.....	.....	.....	.....	.....

Collected May, 1887 (mean of plats O, 21, and 22)[2]	.1119	.0724	.0587	0.0501	0.0418	0.0393	0.0350	0.0361	0.0342	0.0358	0.0376	0.0286
Collected October, 1893 (first to eighth mean of plats 5, 6, 7, 8, 11, 12, 13, 14, 15, 16, 17, and 18, ninth and tenth mean of 5, 6, 7, and 8)	.1125	.0714	.0594	.0474	.0437	.0392	.0386	.0375	.0358	.0358	.....	.....
Average	.1145	.0724	.0598	.0488	.0428	.0393	.0368	.0368	.0350	.0358	.0376	.0286
HOOS FIELD.												
Collected March, 1881:												
Mean of series 1, plats 2 to 6, clover land	.1060	.0633	.0579	.....	.....	.....	.....	.....	.....	.....	.....	.....
Plat O, 5 holes, wheat land	.0969	.0606	.0552	.....	.....	.....	.....	.....	.....	.....	.....	.....
Collected July, 1882 (*Melilotus leucantha* S1, plats 5 and 6; *Trifolium repens* S1, plat 6)	.1116	.0643	.0491	.0440	.0451	.0446	.....	.....	.....	.....	.....	.....
Collected July, 1883:												
Vicia sativa S1, plats 4 and 6; *Trifolium repens* S1, plat 4	.1160	.0715	.0586	.0517	.0451	.0475	.0430	.0482	.0475	.0485	.0527	.0453
Fallow wheat, plat O	.1026	.0629	.0533	.0458	.0472	.0503	.0497	.0424	.0454	.0428	.0491	.0542
Collected July and August, 1885:												
Melilotus leucantha, *Medicago sativa*, and *Trifolium repens*, each S1, plat 5	.1210	.0739	.0650	.0454	.0360	.0487	.0411	.0348	.0255	.0229	.0267	.0205
Fallow wheat, plat O	.1021	.0605	.0486	.0475	.0465	.0402	.0416	.0436	.0420	.0400	.0438	.0461
Collected March, 1868 (barley 4O, 4A, 4AA, and 4C	.1227	.0763	.0656	.....	.....	.....	.....	.....	.....	.....	.....	.....
Collected February and March, 1882 (barley; mean of plats 2 and 4, O, A, AA, AAS, and C	.1094	.0698	.0610	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average	.1098	.0670	.0571	.0469	.0440	.0463	.0439	.0423	.0401	.0386	.0431	.0415
AGDELL FIELD.												
Collected November, 1867 (mean of all 12 plats, after wheat)	.1355	.0766	.0649	.....	.....	.....	.....	.....	.....	.....	.....	.....
Collected October, 1874 (mean of all 12 plats, after clover)	.1246	.0739	.0645	.....	.....	.....	.....	.....	.....	.....	.....	.....
Collected November, 1883, to January, 1884 (mean of all 12 plats, after wheat)	.1219	.0677	.0591	.0513	.0465	.0447	.0437	.0414	.0438	.0441	.0417	.0402
Average	.1273	.0727	.0628	.0513	.0465	.0447	.0437	.0414	.0438	.0441	.0417	.0402
BARN FIELD.												
Collected April, 1870 (mean of plats 4, 5, 6, and 7O, N, A, AC, and C, root land)	.0973	.0674	.0577	.....	.....	.....	.....	.....	.....	.....	.....	.....

[1] In all cases in this table the nitrogen determinations were made by the soda-lime method.
[2] These results also include the percentages of nitrogen in a sample taken at each of the 12 depths from land below plat 3 in March, 1893.

TABLE 29.—*Average weight of fine dry soil and of stones per acre in different experimental fields at Rothamsted and at different depths; also average percentages of nitrogen in the fine dry soils at the respective depths.*

[Summary for each field—Broadbalk, Hoos, Agdell, and Barn fields.]

AVERAGE WEIGHTS OF FINE DRY SOIL PER ACRE.

Depth.	Broadbalk field—samples collected 1865, 1881, 1887, and 1893.	Hoos field—samples collected 1881, 1882, 1883, and 1885 (from leguminous land); 1881, 1883, and 1885 (from wheat fallow); 1868 and 1882 (from barley land).	Agdell field—samples collected 1867, 1874, and 1883–84.	Barn field—samples collected April, 1870 (from root land.	Average of all.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
First 9 inches	2,558,942	2,593,290	2,347,580	2,321,160	2,455,243
Second 9 inches	2,592,259	2,720,656	2,448,399	2,673,095	2,603,602
Third 9 inches	2,814,991	2,890,627	2,532,703	2,650,950	2,722,318
Fourth 9 inches	2,886,339	3,047,939	2,441,895	....	2,792,058
Fifth 9 inches	2,917,681	3,074,563	2,465,262	....	2,819,169
Sixth 9 inches	2,955,543	3,012,298	2,587,276	....	2,851,706
Seventh 9 inches	2,814,612	3,016,107	2,517,401	....	2,782,707
Eighth 9 inches	2,888,789	2,952,629	2,654,461	....	2,831,960
Ninth 9 inches	2,938,868	2,924,185	2,589,332	....	2,817,462
Tenth 9 inches	2,868,118	2,865,290	2,478,854	....	2,737,421
Eleventh 9 inches	2,804,970	2,760,455	2,610,067	....	2,725,164
Twelfth 9 inches	2,795,772	2,817,918	2,644,314	....	2,752,668

AVERAGE WEIGHTS OF TOTAL STONES PER ACRE.

First 9 inches	497,924	480,640	837,352	769,486	646,351
Second 9 inches	443,322	346,120	480,133	530,003	449,894
Third 9 inches	212,655	238,244	363,038	415,488	307,356
Fourth 9 inches	163,867	170,440	476,574	....	270,294
Fifth 9 inches	202,400	164,834	523,083	....	296,772
Sixth 9 inches	144,021	190,302	289,447	....	207,923
Seventh 9 inches	282,083	114,259	472,762	....	289,701
Eighth 9 inches	210,565	141,802	404,655	....	252,341
Ninth 9 inches	162,629	179,368	462,734	....	268,244
Tenth 9 inches	183,930	209,674	528,891	....	307,498
Eleventh 9 inches	137,359	248,766	397,621	....	261,249
Twelfth 9 inches	176,109	204,905	274,700	....	218,571

AVERAGE PERCENTAGES OF NITROGEN IN FINE DRY SOIL.

	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
First 9 inches	0.1145	0.1098	0.1273	0.0973	0.1122
Second 9 inches	.0724	.0670	.0727	.0674	.0699
Third 9 inches	.0598	.0571	.0628	.0577	.0594
Fourth 9 inches	.0488	.0469	.0513	....	.0490
Fifth 9 inches	.0428	.0440	.0465	....	.0444
Sixth 9 inches	.0393	.0463	.0447	....	.0434
Seventh 9 inches	.0368	.0439	.0437	....	.0415
Eighth 9 inches	.0368	.0423	.0414	....	.0402
Ninth 9 inches	.0350	.0401	.0438	....	.0396
Tenth 9 inches	.0358	.0386	.0441	....	.0395
Eleventh 9 inches	.0376	.0431	.0417	....	.0408
Twelfth 9 inches	.0286	.0415	.0402	....	.0368

A study of these tables (28 and 29) will show, in the first place, that in the case of the soils of the first 9 inches, or surface depth, the mean percentages of nitrogen in the soils of each of the fields varies according to the crop grown and according to other circumstances, but that in the subsoils of the second to the sixth or seventh depths it gradually declines, although the mean percentage is very similar at corresponding depths in the three fields—Broadbalk, Hoos, and Agdell. Below the sixth depth, however, there is less evidence of any regular declension either in Hoos or Agdell field, but in the case of the Broadbalk soils the percentages range distinctly lower than in the other fields. Reference to notes made at the time of collection of the samples, however, shows that these lower percentages are to be correlated with larger proportions of sand or chalk intermixed with the clay subsoils, the mingling of chalk especially affecting the lowest depths. It is to be observed that in the case of the other fields the normal clayey subsoil of the six lower depths contains an average of rather over 0.04 per cent of nitrogen, as determined by soda-lime, with little evidence of gradual decline.

NITROGEN AND CARBON IN OTHER CLAYS AND DEEP DEPOSITS.

With reference to this apparently indigenous nitrogen percentage, it should here be recorded that some determinations of nitrogen were made in the Rothamsted laboratory in 1874, in a sample of the Oxford clay obtained in the Sub-Wealden exploration boring at Battle, at a depth of from 500 to 600 feet. This showed, on an average of four closely agreeing analyses, 0.0442 per cent of nitrogen, or very nearly the same proportion as that in the lower clay subsoils at Rothamsted.

Quite recently (June, 1900) Sir Henry Gilbert has obtained from the geological survey office, by the kindness of Sir Archibald Geikie, a number of deposits—some of them clayey, and some highly calcareous—from deep borings, in which he has had determined the nitrogen and organic carbon and the ratios of carbon to nitrogen and of nitrogen to carbon. The results are given in the following table:

TABLE 30.—*Analyses of deep clay deposits compared with average results of deep subsoils at Rothamsted.*

[Percentages of carbonate of lime, nitrogen, and organic carbon in fine dry soil; also ratios of carbon to 1 nitrogen, and of nitrogen to 100 carbon.]

	Carbonate of lime.	Nitrogen (mean).	Organic carbon (mean).	Carbon to 1 nitrogen.	Nitrogen to 100 carbon.
	Per cent.	*Per cent.*	*Per cent.*		
Rothamsted soils, various fields, seventh to twelfth depths *a*	....	0.0450	....	....	....
Oxford clay, Sub-Wealden boring, near Battle, Sussex, 500–600 feet. (Received in 1874)	....	.0442	....	....	....
Oxford clay, Brabourne bore (at 1,370 feet), West Brabourne, Kent	21.35	.0483	0.786	16.3	6.1
Wealden mottled clay, Brabourne boring at 591–611 feet	0	.0343	.533	15.6	6.5
Gault, Meux's Brewery, Tottenham Court Road	30.55	.0397	.613	15.5	6.5
London clay, tunnel for Electric Railway, Piccadilly Circus	7.21	.0412	.391	9.5	10.5

a Deduced from 222 separate samples and 204 nitrogen determinations, made for the most part in duplicate, on a mixture of two or more individual samples from each plat or each depth.

It will be seen that, even at these great depths, far removed from surface influences, we find much the same proportion of nitrogen (viz, about 0.04 per cent) as in the Rothamsted deeper clay subsoils, though we find, it is true, more carbon and higher carbon to nitrogen ratios than in the Rothamsted subsoils.

The general inference would seem to be that in these ancient deposits, whether mere clay or calcareous formations differing much in their general characters, there is a small but fairly constant percentage of nitrogen, viz, about 0.04 per cent, due presumably to the last surviving organic residue of the multitude of animal and vegetable remains accumulated in their suboceanic period. This small percentage of nitrogen, which seems to remain unaltered at a depth of 1,000 feet, seems to be equally unaltered within a few feet of the surface, despite thousands of years of surface vegetation, the influence of which on the permanent organic nitrogen contents of the subsoil seems to be scarcely appreciable below about 4 feet from the surface.

Small as it seems in percentage, the quantity of soil and subsoil nitrogen is enormous. In what precise organic form it exists we do not know, but it seems, except near the surface, to be protected, probably by conditions of temperature and aeration, from the microbic influences which promote the decompositions culminating in nitrification. Indeed, for aught that we know, some part of this clay nitrogen may be in a condition in which it is not even susceptible to such influences. Even in the surface soil, where nitrogen is steadily nitrified (and lost, unless the cropping conditions are favorable to its reassimilation), the nitrates are probably mainly yielded by the old crop residues rather than by this original clay nitrogen. In the Broadbalk field, plat 5—the plat persistently manured with full minerals, but starved for want of nitrogen (see Table 14)—is poorer than its ammonia-fed neighbors in the first 27 inches, but below this it happens to be a good deal richer in total nitrogen than the prosperous adjoining plats. Its crops are starving for want of nitrogen in an assimilable form, and yet it contains in the first three depths (27 inches) 6,401 pounds of nitrogen; in the first 6 feet, 14,056 pounds; and in the first 7½ feet no less than 17,470 pounds of nitrogen per acre. Yet we know from experience that a small top-dressing of sodium nitrate or of ammonium salts would in a single season convert its poor annual yield of 14¾ bushels of grain, with 10½ hundredweight of stunted straw per acre, into a rich crop of probably 35 bushels of grain per acre, with a luxuriant growth of straw.

Nature is niggardly, then, in her annual dole from this great store. What does she spare us, and how?

We have among the Rothamsted records sufficient data relating to land unmanured with nitrogen to enable us to answer this question, but before passing on to it we may properly stop to consider the results indicating the "nitric" nitrogen, or nitrogen existing as nitrates, in the different soils and subsoils.

NITROGEN AS NITRATES ("NITRIC" NITROGEN).

GENERAL DISCUSSION AND FULL STATEMENT OF ANALYTICAL RESULTS ON THE BROADBALK SOILS.

The great classical researches that have been made at Rothamsted on the subject of nitrification—nature's way of providing food for new vegetable life from the débris of preceding life—are already well known to you in substance. The subject was very carefully and thoroughly dealt with in the lectures delivered to you by Professor Warington in 1891, and the chief outcome of its study was again summarized in the course of Sir Henry Gilbert's lectures. Some apology—as indeed also in the case of the preceding pages dealing with organic nitrogen—would be due from me for again traveling over ground that has been already explored and explained, but for the fact that I am in the position of bringing before you in these 1893 samples the latest confirmatory evidence directly yielded by the soil itself of many facts that were already known to us. Sir Henry Gilbert summed up to you the practical results of fifty years' continuous wheat growing under so many different manurial conditions; but he was unable to give you the results of the examination of the soils at the end of the fifty years, for the samples, as I have said, were actually being collected while he was with you. Then, as at the time of Professor Warington's lectures, the 1881 samples formed the most recent complete set of Broadbalk samples that had been examined. The consideration, therefore, of the later, and much more complete results of the analyses of the 1893 samples, taken at the end of the first fifty years of the experiments, may be regarded as a continuation (completion would be far too comprehensive a word) of Sir Henry Gilbert's review of the results of fifty years' work at Rothamsted. The conclusions deduced from the study of the determinations of nitric nitrogen in the 1893 samples are not qualitatively different from those deduced from the samples collected in 1881; but the plats in 1893 were all twelve years older, and the evidence they have to give us is entitled to still more of the respect due to age than that gathered at the earlier period.

It will be convenient to extract from Tables 11 and 12 the figures relating to nitric nitrogen, so as to have them before us in a more condensed form, and also as we go on to make further selected extracts from them for the purpose of comparing various plats one with another.

TABLE 31.—*Broadbalk wheat soils, samples collected October 13–21, 1893—Parts per million of* NITROGEN *as* NITRATES *in fine dry soil.*

Plat.	Manure per acre per annum.	Nitrogen in manure per acre per annum.	First depth.	Second depth.	Third depth.	Fourth depth.	Fifth depth.	Sixth depth.	Seventh depth.	Eighth depth.	Ninth depth.	Tenth depth.
		Pounds.	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*
2a	Farmyard manure since 1884	200	9.43	8.48	3.68							
2b	Farmyard manure 50 years	200	4.51	16.98	4.39							
3	Unmanured	0	3.72	3.45	.98							
4	Unmanured since 1852	0	3.07	2.63	.76							
5	Full minerals	0	4.06	2.38	.80	0.34	0.35	0.25	0.36	0.32	0.29	0.19
6	Full minerals and ammonium salts	43	5.45	4.77	2.08	1.07	1.21	1.31	1.14	.66	.82	.72
7	Full minerals and ammonium salts	86	5.77	7.19	3.06	1.91	1.62	1.55	1.58	1.40	1.43	1.46
8	Full minerals and ammonium salts	129	6.71	10.92	3.12	3.13	2.97	2.63	2.80	2.65	2.04	1.88
9a	Full minerals and sodium nitrate	43	6.41	7.20	2.40							
9b	Sodium nitrate only	43	4.28	13.05	5.58							
10a	Ammonium salts (no minerals since 1844)	86	4.83	9.52	4.03							
10b	Ammonium salts (no minerals since 1850)	86	3.64	10.89	5.01							
11	Phosphates and ammonium salts	86	4.50	9.20	5.33	4.19	3.00	1.77	1.57	2.13		
12	Phosphates, sodium and ammonium salts	86	5.46	9.54	4.35	2.68	2.04	1.78	1.88	1.85		
13	Phosphates, potassium and ammonium salts	86	5.37	9.79	3.38	1.68	1.23	1.34	1.24	1.24		
14	Phosphates, magnesium and ammonium salts	86	5.16	11.60	4.22	2.46	2.13	1.90	1.97	2.37		
15	Full minerals and ammonium salts (autumn)	86	3.86	7.00	3.77	2.34	1.89	1.52	1.78	1.33		
16	Full minerals and sodium nitrate since 1884	86	5.24	15.94	7.44	4.68	2.73	2.10	1.91	2.19		
17	Full minerals and ammonium salts transposed in alternate years	*a* 86	4.70	10.37	3.06	1.03	.64	0.61	0.48	0.60		
18			4.49	15.53	2.29	1.21	1.02	.58	.50	.50		
19	Rape cake	93	8.55	9.12	5.08							

a Plat 18 received the 86 pounds nitrogen in the form of ammonium salts for the crop of 1893.

TABLE 32.—*Broadbalk wheat soils, samples collected in October, 1893*—NITROGEN *as* NITRATES *in pounds per acre.*

Plat.	Manure per acre per annum.	Nitrogen in manure per acre per annum.	First 9 inches.	Second 9 inches.	Third 9 inches.	Fourth 9 inches.	Fifth 9 inches.	Sixth 9 inches.	Seventh 9 inches.	Eighth 9 inches.	Ninth 9 inches.	Tenth 9 inches.	Summary. First to third 9 inches.	Summary. First to eighth 9 inches.	Summary. Ninth and tenth 9 inches.	Summary. First to tenth 9 inches.
2a	Farmyard manure since 1884	200	23.67	22.65	10.27	......	......	......	......	......	......	......	56.59	......	......	......
2b	Farmyard manure 50 years	200	10.53	45.36	12.25	......	......	......	......	......	......	......	68.14	......	......	......
3	Unmanured	0	9.64	9.22	2.74	......	......	......	......	......	......	......	21.60	......	......	......
4	Unmanured since 1852	0	7.96	7.03	2.12	......	......	......	......	......	......	......	17.11	......	......	......
5	Full minerals	0	10.53	6.36	2.23	0.95	1.00	0.71	1.03	0.92	0.87	0.57	19.12	23.73	1.44	25.17
6	Full minerals and ammonium salts	43	14.13	12.74	5.81	2.98	3.47	3.72	3.25	1.89	2.46	2.16	32.68	47.99	4.62	52.61
7	Full minerals and ammonium salts	86	14.96	19.21	8.54	5.32	4.64	4.40	4.51	4.02	4.29	4.38	42.71	65.60	8.67	74.27
8	Full minerals and ammonium salts	129	17.40	29.17	8.71	8.71	8.51	7.46	7.99	7.60	6.13	5.64	55.28	95.55	11.77	107.32
9a	Full minerals and sodium nitrate	43	16.62	19.23	6.70	......	......	......	......	......	......	......	42.55	......	......	......
9b	Sodium nitrate only	43	11.10	34.86	15.58	......	......	......	......	......	......	......	61.54	......	......	......
10a	Ammonium salts (no minerals since 1844)	86	12.52	25.43	11.25	......	......	......	......	......	......	......	49.20	......	......	......
10b	Ammonium salts (no minerals since 1850)	86	9.44	29.06	13.99	......	......	......	......	......	......	......	52.49	......	......	......
11	Phosphates and ammonium salts	86	11.67	24.58	14.88	11.66	8.60	5.02	4.48	6.11	......	......	51.13	87.00	......	......
12	Phosphates, sodium, and ammonium salts	86	14.16	25.48	12.14	7.46	5.85	5.05	5.36	5.31	......	......	51.78	80.81	......	......
13	Phosphates, potassium, and ammonium salts	86	13.92	26.15	9.44	4.68	3.52	3.80	3.54	3.56	......	......	49.51	68.61	......	......
14	Phosphates, magnesium, and ammonium salts	86	13.38	30.99	11.78	6.85	6.10	5.39	5.62	6.80	......	......	56.15	86.91	......	......
15	Full minerals and ammonium salts (autumn)	86	10.01	18.70	10.52	6.51	5.42	4.31	5.08	3.81	......	......	39.23	64.36	......	......
16	Full minerals and sodium nitrate since 1884	86	13.59	42.58	20.77	13.03	7.82	5.96	5.45	6.28	......	......	76.94	115.48	......	......
17	Full minerals and ammonium salts transposed in alternated years	*a* 86	12.19	27.70	8.54	2.87	1.83	1.73	1.37	1.72	......	......	48.43	57.95	......	......
18			11.64	41.49	6.39	3.37	2.92	1.65	1.43	1.43	......	......	59.52	70.32	......	......
19	Rape cake	93	22.06	24.36	14.18	......	......	......	......	......	......	......	60.60	......	......	......

a Plat 18 received the 86 pounds nitrogen in the form of ammonium salts for the crop of 1893.

It happens, somewhat unfortunately, that the season preceding the taking of the samples in October, 1893, was far from being a normal season. The rainfall for the harvest year—September, 1892, to August, 1893, inclusive—was only 24 inches, as against an average, for the preceding seventeen years, of nearly 30 inches. The deficiency was chiefly in March, April, May, and June. During the whole of these four months less than 3 inches of rain fell, whereas there is normally from 8 to 9 inches during the same period. As a consequence, the crop of 1893, preceding the taking of the samples, was a miserably small one, averaging all round only about 60 per cent of an average crop of grain and only 40 per cent of the average quantity of straw. From the point of view of analytical investigation, however, it is to some extent a matter of regret that after harvest and before the soil sampling in 1893, there was a somewhat heavy rainfall, viz, 4½ inches, while a further fall of three-fourths of an inch took place during the period of sampling. Owing to this, much of the nitrogen that would in autumn be ordinarily found in the surface soil was no doubt washed downward into the second depth. The third depth, too, shows more than would probably be ordinarily found, and it will be seen that there is, as a rule, a very distinct break in continuity between the third and fourth depths.

In regarding the results relating to the deeper layers of the subsoil, it must be remembered that the field is artificially drained, and that it is at about the bottom of the third depth, or at 27 inches, that the soil water is tapped by the drainpipes whenever they run. Much of the rainfall must percolate downward into the lower subsoil without emerging from the drainpipes, which in a close soil like this, only run when rain is heavy or continuous. But the sudden decrease that we observe in many cases, in looking down the figures, in passing from the third to the fourth depth, seems to be attributable in a great measure to the position of the drains, though it is also to be remembered that below the drains, we are also well below the depth at which the wheat roots collect the greater part of their food. Nitrification goes on mainly, though probably not exclusively, in the surface soil, or in the upper depths of the subsoil. Such of the nitrates (or, for convenience, let us say such of the nitric nitrogen) as is not utilized by the growing wheat (which ceases to take up nitrogen actively some time before it is ready to cut) is gradually washed down. Some of this emerges in the pipe drainage should there be heavy rain, and what does not escape in this way must percolate downward into the subsoil together with any such small quantity of nitric nitrogen as may be formed in the subsoil itself.

In the absence of other evidence it might appear possible that the break observed between the third and fourth depths was due to retention by the growing crop of the nitrates present or formed in the upper depths during the growing season, which retention would aturally limit the downward percolation into the subsoil prior to arvest, while the nitrates subsequently formed in the surface soil vould hardly have had time to penetrate into the fourth depth.

But the Rothamsted studies of nitrification, as you may remember, ave not been confined to the Broadbalk field, but have been extended) the examination to an even greater depth of the subsoil of land hat does not happen to be pipe drained. Some of the results of hese studies are given in Sir Henry Gilbert's lectures, delivered in 893.[1] From those results it will be seen that where there is no pipe rainage there has not been a break in the amount of nitric nitrogen bout or below the third depth of 9 inches. This seems to support ne conclusion that the sudden reduction shown in the Broadbalk amples of 1893, between the third and fourth depths, is largely due) the tapping of the drainage water by the drainpipes.

DOES NITRIFICATION OCCUR IN THE LOWER SUBSOILS?

Looking generally at the tables it will be seen that, as in the deep eries of plats previously examined, as described in Sir Henry Gilert's lectures, nitric nitrogen is found down to the lowest depth ampled. The question arises, how far is this due to percolation, or ow far is its presence due to the nitrification going on in the subsoil self? It has certainly been experimentally ascertained at Rothamted that the nitrogen of the subsoils is at any rate to some extent usceptible of nitrification if the organisms are actually present and nder the other conditions of aëration and temperature necessary for itrification. It has even been proved that the nitrifying organisms o actually exist in the deep subsoils, though they seem to be very ew and very feeble as compared with those found in the upper epths, especially in the surface soil. But even if the actual condiions naturally existing in the subsoil allow of any appreciable nitrifiation in the lower depths, it would seem to be very feeble.

If we take, for example, the case of plat 5, which receives no nitrognous manure, and which is liberally supplied with mineral manures,) as to facilitate as fully as possible the utilization of the nitric itrogen produced by nitrification in the surface soil and upper subil, we find that the nitric nitrogen existing below the drainpipes verages less than 1 pound per acre (actually 0.87 pound) in each epth of 9 inches. Now in the unmanured wheat fallow soil of Hoos eld, sampled in July, 1883 (see Sir Henry Gilbert's lectures, p. 113), he average quantity of nitric nitrogen was nearly 2½ pounds per cre in each of the nine depths below the first 27 inches. In that case

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 22, Tables 43 and 44, pp. 13–115. Also paper "On some points in the composition of soils, with results lustrating the source of the fertility of Manitoba prairie soils." (Journal of the hemical Society of London, Transactions, 47 (1885), p. 380.)

there were no drainpipes to tap the soil higher up. It is also to be noted that the samples were taken in a fallow year (the plat being wheat cropped and fallowed in alternate years), and that, therefore, there had been no growing crop to assimilate the surface-formed nitrates. On the other hand, the sampling was carried out in July, when summer nitrification was very far from being completed, while the samples from the Broadbalk field now under consideration were taken in October, i. e., nearly three months after the crop would have been actively engaged in taking up nitrogen, though nitrification would have been, during these three months, in active progress.

On the whole it would seem, in the light of the 1893 samples, that the larger quantity of nitric nitrogen found in the lower depths of Hoos field was partly related to the absence of a recently growing crop, but more particularly to the absence of artificial drainage.

In another series of samples, taken toward the close of 1882 in Agdell rotation field, after wheat following fallow,[1] the average quantity of nitric nitrogen in the nine depths below the first 27 inches was 1.3 pounds per acre. Here again, though there had been a growing crop, there was no artificial drainage, and its absence coincides with the greater quantity of nitric nitrogen than we find in the lower depths of the Broadbalk plat unmanured with nitrogen.. The six consecutive depths below the drainpipes on plat 5 of the Broadbalk field in 1893 contained 6.05 pounds of nitric nitrogen per acre; the corresponding depths of Hoos field (wheat fallow, sampled in July, 1893) contained 15.49 pounds per acre.

From the quantity of nitrates actually found in the waters collected from the drainpipes of the Broadbalk field during some years it is estimated that sometimes nearly 17 pounds of nitrogen per acre have passed away in drainage from the wholly unmanured plats, and over 18 pounds per acre from plat 5, which we are at the moment considering. Bearing this in mind, and also the difference of conditions in the other fields, there can be little doubt that the larger quantity of nitric nitrogen found in their lower depths, and the absence of any marked break between the third and fourth depths is due to downward percolation.

Quite apart from other evidence the examination of the lower depths of the ammonia-manured plats, which will be considered presently, shows very clearly that the drainpipes are very far from being able to remove completely the nitrates produced by the oxidation of unused ammonium salts and of crop residues in the soils fed with such salts, for we find largely increased nitric nitrogen, despite the drainpipes, all the way down to 90 inches. It seems, therefore, only reasonable to assume that even on the unmanured plats, as nitrates occur to so large an extent in the actual drainage water collected from the pipes, a considerable quantity must be carried down in the undis-

[1] Journal of the Chemical Society of London, Transactions, 47 (1885), p. 406.

charged drainage water that indubitably finds its way down to the chalk below. Some allowance, then, must be made for this in regarding the 0.87 pound of nitric nitrogen per acre found in each depth of the lower subsoil of plat 5, and such allowance, whatever it be, would reduce to very small dimensions the nitric nitrogen that could be attributed to actual subsoil nitrification.

Furthermore, if we turn to the results obtained from the drain gauges we fail to find practical evidence of any very appreciable subsoil nitrification. The structure of the Rothamsted drain gauges is familiar to many of you. Each of these three gauges incloses an area of natural soil with its natural subsoil, the area of each being one one-thousandth of an acre, and so constructed that all the rainfall which percolates through them can be collected for measurement and analysis. In all three the soil is kept fallow, and they differ only in depth, containing respectively 20, 40, and 60 inches of soil. Now, if nitrification went on appreciably in the subsoil, we should expect to find more nitric nitrogen in the drainage water from the deepest gauge than in that from the shallowest As a matter of fact this is not the case. During the twenty years from 1877–78 to 1896–97 the nitric nitrogen yielded annually by the shallowest and the deepest gauges has been as follows:

TABLE 33.—*Rothamsted drain gauges.*

	Pounds.
20-inch gauge	35.07
60-inch gauge	33.87

And, as is pointed out in the Rothamsted "Memoranda" for the current year, the conditions of aeration are distinctly more favorable in the drain gauges than in the field.

On the whole, then, we may consider that under natural field conditions the vast stores of subsoil nitrogen within the reach even of the deeply rooting wheat plant are, for all practical or economical purposes, unavailable for appreciable contribution to the nitrogenous sustenance of the crop.

The conclusion is not new, but the subject appears to be one of sufficient magnitude to justify the space that I have been tempted to occupy in examining the latest contributions to the evidence that seems to bear upon it.

NITRIC NITROGEN IN THE UNMANURED AND THE DUNGED PLATS AND THE RAPE-CAKE PLAT.

When we come to a detailed consideration of the results we are, as in the consideration of the total nitrogen contents, naturally led to compare first the persistently unmanured plats 3 and 4 with the two dunged plats, 2a and 2b. Here we much regret the absence of deeper samples. As it is, we must be content in the case of these, as in the case of four of the other plats, with the results for the first 27 inches. We may also here consider the rape-cake plat. It is convenient to tabulate the results separately.

TABLE 34.—*Broadbalk wheat soils, plats 3, 4, 2a, 2b, and 19*—NITROGEN *as* NITRATES (*"nitric" nitrogen) in samples collected in October, 1893.*

Depth.	Plat 3, unmanured 50 years.	Plat 4, unmanured since 1852.	Plat 2a, 14 tons farmyard manure, 9 years.	Plat 2b, 14 tons farmyard manure, 50 years.	Plat 19, rape-cake plat.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
First 9 inches	9.64	7.96	23.67	10.53	22.06
Second 9 inches	9.22	7.03	22.65	45.36	24.36
Third 9 inches	2.74	2.12	10.27	12.25	14.18
1 to 27 inches	21.60	17.11	56.59	68.14	60.60

We see that even on the land wholly unmanured for fifty years, notwithstanding the recent removal of the fiftieth continuous wheat crop, the uppermost 27 inches contained 21.60 pounds of nitric nitrogen per acre, equivalent to 1¼ hundredweight per acre of commercial nitrate of soda. Of this the greater part is in the upper 18 inches.

Unfortunately this autumnal store of nitrates is destined for the most part to be washed away before the young wheat plant is old enough to appropriate much of it, and it is mainly on the nitrates formed in the spring and early summer that the crop lives. Of course in a fairly dry winter much of the autumn nitrates may be retained, and when this is the case the crop is benefited by food that in a wet winter would be wasted. It is, however, remarkably interesting to find that on a soil absolutely unmanured and continuously cropped for fifty years there should still be found within 18 inches of the surface, from two to three months after harvest, as much nitrate as would be annually carried off in a year's crop.

It will be seen later that the quantity found in the surface soil is practically the same as at the same time of year in 1881, twelve years earlier, and the quantity found in the first 27 inches is not very different; and if we allow for the fact that the soil had in 1881 been very heavily rained on between harvest and the time of sampling the general similarity of the results is increased.

Plat 4, though unmanured since 1852, was in its earlier years manured with superphosphate and ammonium sulphate. Although so many years have elapsed, plat 4 has (see Table 1) on the average yielded distinctly larger crops than plat 3, its superiority in yield of grain having persisted longer than in that of straw. In 1893, which was a very bad harvest year owing to summer drought, plat 4 had yielded 2 bushels per acre more grain than plat 3, and it is noteworthy that we find in it some 4½ pounds less of nitric nitrogen in the first 27 inches than we find in plat 3.

One is naturally struck with the fact that, in the first 9 inches, plat 2b—the richer land—should show less than half the nitric nitrogen shown in its less rich neighbor, plat 2a; but this may be due to mere accident of the distribution of the rainfall during the time of sampling. If we regard the first and second depths conjointly, we find that plat 2b contains nearly 56 pounds of nitric nitrogen per acre as against 46 pounds in plat 2a. The nitric nitrogen in the first 18 inches of the continuously dunged plat is equal to more than 3 hundredweight per acre of nitrate of soda, while, if the third depth be included, the quantity of nitric nitrogen in the 27 inches is equal to nearly 4 hundredweight of nitrate of soda per acre. But how transient this surface richness is, and how readily and rapidly it escapes downward, is seen by the fact that, under the influence of recent rain, the actual surface soil—the first 9 inches—is already scarcely richer than that of the wholly unmanured plat 3. Only 10.53 pounds out of the 68 pounds contained in the first 27 inches remained at the time of sampling in the surface soil. The bulk of the recently formed nitrates had already sunk into the second 9 inches, and we may take it that a winter sampling would probably have revealed much less nitric nitrogen in the second depth.

The rape-cake plat is rich in surface nitrates, and in all three depths it closely resembled, in 1893, the dunged plats, being intermediate in richness between the continuously dunged plat and the plat dunged for nine years only.

THE CHEMICALLY MANURED PLATS.

We will now examine the data obtained from the various chemically manured plats. The first series that it is convenient to consider is the series of plats 5 to 8, all receiving a full dressing of superphosphate, potassium, sodium, and magnesium salts ("full minerals"), but with and without various dressings of ammonium salts applied under similar conditions in the spring. For comparison we will also again include plat 3.

TABLE 35.—*Broadbalk wheat soils, plats 3, 5, 6, 7, and 8*—NITROGEN *as* NITRATES (*"nitric" nitrogen*) *in samples collected in October, 1893.*

Depth.	Plat 3, unmanured.	Plat 5, full minerals; no nitrogen since 1851.	Plat 6, full mineral manures and ammonium salts containing 43 pounds of nitrogen per acre.	Plat 7, full mineral manures and ammonium salts containing 86 pounds of nitrogen per acre.	Plat 8, full mineral manures and ammonium salts containing 129 pounds of nitrogen per acre.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
First 9 inches	9.64	10.53	14.13	14.96	17.40
Second 9 inches	9.22	6.36	12.74	19.21	29.17
Third 9 inches	2.74	2.23	5.81	8.54	8.71
Fourth 9 inches	.....	.95	2.98	5.32	8.71
Fifth 9 inches	.....	1.00	3.47	4.64	8.51
Sixth 9 inches	.....	.71	3.72	4.40	7.46
Seventh 9 inches	.....	1.03	3.25	4.51	7.99
Eighth 9 inches	.....	.92	1.89	4.02	7.60
Ninth 9 inches	.....	.87	2.46	4.29	6.13
Tenth 9 inches	.....	.57	2.16	4.38	5.64
1 to 27 inches	21.60	19.12	32.68	42.71	55.28
1 to 72 inches	.....	23.73	47.99	65.60	95.55
1 to 90 inches	.....	25.17	52.61	74.27	107.32

Plat 5 has already been discussed partially in the present section, and also under the subject of total nitrogen. This plat has had no ammonium salts for forty-two years prior to 1893. It has, however, yielded persistently higher crops than the unmanured plat, the minerals, no doubt, having enabled it to take greater advantage of the moderate quantity of nitrates produced from the soil. In the six years 1889–1894, it averaged 1⅝ bushels of grain and 1⅜ hundredweight of straw more than plat 3.

We have seen that, in virtue of this greater annual yield, there has been less loss of surface nitrogen than on plat 3, a distinctly larger percentage of total nitrogen being now found in the surface soil of plat 5 than in that of plat 3.

We find in 1893, in the surface soil of plat 5, slightly more nitric nitrogen than in that of plat 3, though in the first 27 inches the quantity is rather less than in plat 3, being intermediate between that in plats 3 and 4.

More interesting is the study of plats 6, 7, and 8 in relation to plat 5, and for all of these we have fortunately full sets of samples down to a depth of 7½ feet. The figures speak so plainly for themselves as they stand in Table 35 that it seems scarcely necessary to enlarge upon them. The surface soils are all richer than on plat 5. If, however, we take the first and second depths together, containing respectively in plats 5, 6, 7, and 8, 16.89 pounds, 26.87 pounds, 34.17 pounds, and 46.57 pounds of nitric nitrogen per acre; or the first 27 inches, containing respectively 19.12 pounds, 32.68 pounds, 42.71 pounds, and 55.28 pounds per acre; we at once see that there is a difference according remarkably with the sequence of the increasing annual supply of ammonium salts. We see, further, the same constant differences in nitric nitrogen in the lower depths, down to the tenth or lowest depth sampled. And if we take the whole 7½ feet comprised in the ten depths, we find per acre in plats 5, 6, 7, and 8, 25.17 pounds, 52.61 pounds, 74.27 pounds, and 107.32 pounds of nitric nitrogen.

If we deduct from the three latter plats the nitrogen of plat 5, we find in round numbers as follows, in the three plats receiving respectively 43 pounds, 86 pounds, and 129 pounds of nitrogen per acre per annum as ammonium salts.

TABLE 36.—*Excess of nitric nitrogen in plats 6, 7, and 8, over that in plat 5.*

	Plat 6.	Plat 7.	Plat 8.
	Pounds.	*Pounds.*	*Pounds.*
Nitrogen in ammonium salts supplied per acre per annum	43	86	129
Nitric nitrogen per acre found in soils and subsoils to a depth of 90 inches, in excess of plat 5, receiving no ammonium salts	26½	49	82

The consistency of these differences is fairly well maintained in each of the successive sectional depths.

The difference between plats 6 and 7 is almost exactly proportional to the annual dressings of ammonium salts applied to the two plats, and also proportional to the increase of crops obtained under their respective influence. But in plat 8, where the still further increase in the annual dressing of ammonium salts, although it produces an increase in crop, does not produce a proportional increase, but is relatively more wasteful, the quantity of unutilized nitrates in the soil is relatively considerably greater. It is also to be noticed that there is a much greater decline below the depth of the pipe drainage in plats 6 and 7 than in the case of plat 8, where the application of ammonium salts is admittedly excessive. As the chalk occurs not very far below the tenth depth, drainage would go on freely below, and it is clear that there would be great loss by natural drainage during the winter months of much rain and in the absence of an actively feeding crop to consume the nitrates at the surface. It is of course this winter drainage that involves the great loss of soil and manurial nitrogen which necessarily occurs in the growth of wheat and similar cereal crops.

The autumn application of ammonium salts, though still experimentally maintained on plat 15, has long been abandoned in practical farming. Its wastefulness is shown by the relative crop records of this plat, as compared with plat 7, similarly manured but receiving its ammonium salts in the spring (see Table 1). Indeed, it is largely the experience gained at Rothamsted that led to the abandonment in modern farming practice of the autumn application of ammonium salts.

The nitric nitrogen found in October is less on the plat that receives its nitrogenous dressing in the autumn; but at the time of sampling the annual dressing of ammonium salts had not been applied, and much nitrification would occur subsequently to the application of the ammonium salts at the end of October if the rest of the autumn were mild, and consequently greater loss of nitrogen would occur during the winter rains than on the spring-dressed plat.

It is observed at Rothamsted, when ammonium salts are applied, say, at the end of October, that if the drainpipes happen to run within a week or two of the sowing, the first collection of the drainage water will show traces of ammonia; but that if there be only a day or two of continuous drainage, even so late in the year, the ammonia often wholly disappears, the whole of the nitrogen in the drainage being already converted into nitrates. Indeed, in the earlier years of the experiments, when the ammonium salts were throughout for the most part applied in autumn, the quantity of nitric nitrogen in the winter drainage of the different plats obviously bore a very direct relation to the quantities of ammonium salts applied.

The application of ammonium salts is, in fact, virtually tantamount to an application of nitrate, and it is only because ammonium salts are capable of such rapid conversion into nitrate that they give in practical farming, under favorable conditions of soil and weather, results closely approaching those obtained by the application of sodium nitrate itself.

COMPARISON OF PLATS RECEIVING AMMONIUM SALTS AND SODIUM NITRATE, RESPECTIVELY.

It is of interest to compare the plats receiving their nitrogen as ammonium salts with those receiving a corresponding quantity of sodium nitrate. These are plats 6 and 9a, receiving 43 pounds of nitrogen annually per acre; and plats 7 and 16, receiving 86 pounds of nitrogen per acre per annum, full minerals being also supplied in all cases. We have also plat 9b receiving 43 pounds of nitrogen per acre per annum as sodium nitrate, but without any mineral manures.

TABLE 37.—*Broadbalk wheat soils, plats 6, 9a, 9b, 7, and 16*—NITROGEN *as* NITRATES (“*nitric*” *nitrogen*) *in samples collected in October, 1893.*

Depth.	Plat 6, full minerals, with 43 pounds nitrogen per acre as ammonium salts.	Plat 9a, full minerals, with 43 pounds nitrogen per acre as sodium nitrate.	Plat 9b, no minerals, 43 pounds nitrogen per acre as sodium nitrate.	Plat 7, full minerals, with 86 pounds nitrogen per acre as ammonium salts.	Plat 16, full minerals, with 86 pounds nitrogen per acre as sodium nitrate.
Nitric nitrogen, per acre, in 1893 samples:	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
First 9 inches	14.13	16.62	11.10	14.96	13.59
Second 9 inches	12.74	19.23	34.86	19.21	42.58
Third 9 inches	5.81	6.70	18.58	8.54	20.77
Fourth 9 inches	2.98			5.32	13.03
Fifth 9 inches	3.47			4.64	7.82
Sixth 9 inches	3.72			4.40	5.96
Seventh 9 inches	3.25			4.51	5.45
Eighth 9 inches	1.89			4.02	6.28
1 to 27 inches	32.68	42.55	61.54	42.71	76.94
1 to 72 inches	47.94			65.60	115.48
Annual produce per acre, six years, 1889-1894:					
Grain	1,598	1,807	1,126	2,113	2,070
Straw	2,436	3,362	1,932	3,766	4,270
Total	4,034	5,169	3,058	5,879	6,340

Comparing plats 6 and 9a, we find that in the first 27 inches of the nitrated plat 9a there are about 10 pounds more of nitric nitrogen per acre than in the ammonium-salts plat, both plats having received the same dressing of nitrogen, but in different forms. As this excess is found mainly in the two upper depths, it seems scarcely likely that it is wholly or even mainly due to the resting on the surface soil of the actual nitrate sown in the spring. The nitrated plat 9a is a great deal more fertile than the ammonium-salts plat, and it seems just possible that the greater richness of plat 9a in nitric nitrogen in October may be related to the greater fertility persistently maintained on plat 9a by the use of nitrate and the consequently greater richness of the soil in crop residue, and therefore in organic nitrogen, and to the nitrification or oxidation of this residue. On the other hand, it may well be attributable to the creeping upward, under the influence of hot weather, of nitrates which may have been washed down earlier.

Up to 1884, plats 9a and 9b received twice the quantity of sodium nitrate that they had received for the nine years immediately prior to 1893, so that the greater accumulation of crop residue in plat 9a is no doubt partly attributable to more liberal treatment in the past.

Plat 9b gets the same dressing of sodium nitrate as plat 9a, but without any mineral manures, and gives naturally much poorer crops year by year. Consequently it is poor in organic crop residues. In the first 27 inches it contained, in 1893, 61½ pounds of nitric nitrogen per acre, or 19 pounds more than its brother plat 9a. Unlike the case of 9a, most of the nitric nitrogen is found in the second and third depths. It seems that in plat 9a more of the applied nitrate has been used and less washed into the second and third depths. On plat 9b, where there is less utilization, we find much of the residue of the unused nitrate in the subsoil; but in the surface soil, at this late period of the year (October), there is less nitric nitrogen, possibly because there is less crop residue and less oxidation. Doubtless, if we had samples of the lower depths we should find much more nitrate that has been wasted for lack of mineral food to enable the crops to take it up.

As may be seen hereafter, the analyses of the soils of these two plats in 1881 showed very similar results, as was very clearly pointed out to you in Professor Warington's lectures dealing with the subject of nitrification.

When we turn to plats 7 and 16, similarly manured to plats 6 and 9a, but with twice the quantities of ammonium salts and of sodium nitrate, respectively, we find not a great deal of difference in the surface soil. In the subsoil, however, we find in the second 9 inches more than twice as much nitric nitrogen on the nitrated plat 16 as on the ammonia-manured plat 7, and about 2½ times as much in the third depth. Then we have a great decrease as we pass the level of the drainpipes; still the fourth depth contains about 2½ times as much on plat 16 as on plat 7, and although the difference becomes then less, there is much more nitric nitrogen in each succeeding depth as far as we go. In the first 27 inches plat 16 contains about 34 pounds more nitric nitrogen per acre than plat 7, and in 72 inches about 50 pounds more, equivalent to about 3 hundredweight of commercial nitrate of soda; a good deal of which nitric nitrogen has sunk too low for there to be much hope of its future recovery, and is as virtually lost as though it had escaped by way of the drainpipes. It should be mentioned that the crop on plat 16 was very poor, having been injured by so heavy an application of manure in a dry season.

It is not remarkable, after an annual spring dressing of 550 pounds per acre of sodium nitrate, to find a large quantity of the necessarily unassimilated nitrate in the subsoils, but as somewhat more nitrogen is usually assimilated on the nitrated plat than on the ammonium salts plat the annual loss of nitrogen must be greater on plat 7 than on plat 16, yet we find less nitrates in the subsoil. It is true that under the unusual influences of the dry summer of 1893 the crop of plat 9a was exceptionally small, being less than that of plat 7. The difference in nitrogen assimilation, however, does not account for the discrepancy. It may be that the complete nitrification of the ammonium salts is not always as rapid as we know it to be sometimes, and that some of the ammonia supplied in the spring is still held in some form of temporary combination in the soil. The drainage waters show that ammonium salts are not removed, as such, in solution. Their nitrification might be thus protracted, and their passage downwards as nitrate be more distributed over the year than is the downward passage of the nitrogen applied as sodium nitrate.

The spring and summer of 1893 were excessively dry, and not favorable to the rapid nitrification of ammonium salts. If the examination of the soils was carried out in another season we might find relatively more nitrate in the subsoils of the ammonia-dressed plats. There is no evidence of permanent accumulation of ammonium salts, as such, in the soils; but there may be temporary accumulation. If the large unused excess is not wholly converted into nitrates we should seem to be driven to suppose that some of it is lost by decomposition into free nitrogen—of which decomposition, however, there is no evidence, except where there is a large excess of organic matter like dung.

COMPARISON OF PLATS RECEIVING LIKE DRESSINGS OF AMMONIUM SALTS BUT WITH VARYING MINERAL TREATMENT.

We will now turn to the series of plats all receiving the same dressing per acre of ammonium salts, but differing as to mineral treatment. The nitric nitrogen results for these plats are shown in the following table:

TABLE 38.—*Broadbalk wheat soils, plats 3, 10a, 10b, 11, 12, 13, and 14*—NITROGEN *as* NITRATES (*"nitric" nitrogen*) *in samples collected October, 1893.*

Depth.	Plat 3, unmanured 50 years.	Receiving anually 400 pounds ammonium salts containing 86 pounds nitrogen per acre.					
		Plat 10a, with no mineral manure since 1844.	Plat 10b, with no mineral manure since 1850.	Plat 11, with superphosphate.	Plat 12, with superphosphate and sodium salts.	Plat 13, with superphosphate and potassium salts.	Plat 14, with superphosphate and magnesium salts.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
First 9 inches	9.64	12.52	9.44	11.67	14.16	13.92	13.38
Second 9 inches	9.22	25.43	29.06	24.58	25.48	26.15	30.99
Third 9 inches	2.74	11.25	13.99	14.88	12.14	9.44	11.78
Fourth 9 inches	......	......	......	11.66	7.46	4.68	6.85
Fifth 9 inches	......	......	......	8.60	5.85	3.52	6.10
Sixth 9 inches	......	......	......	5.02	5.05	3.80	5.39
Seventh 9 inches	......	......	......	4.48	5.36	3.54	5.62
Eighth 9 inches	......	......	......	6.11	5.31	3.56	6.80
1 to 27 inches	21.60	49.20	52.49	51.13	51.78	49.51	56.15
28 to 72 inches	......	......	......	35.87	29.03	19.10	30.76
1 to 72 inches	......	......	......	87.00	80.81	68.61	86.91

In 1893 there was an underaverage crop and an underaverage rainfall, and therefore less than average utilization of nitrates and probably later and less complete nitrification, and certainly less than average loss by drainage and downward percolation. The crop of the following year was a comparatively large one—far above average—and evidently got the benefit of much nitrogen that would after an ordinary season have been lost.

Most of the unused nitrates are seen to be in the second depth. In the surface depths the poorest plats—excluding, of course, plat 3, which is placed in the table for comparison only—are plats 10a, 10b, and 11. The last-named, which, with ammonium salts, receives only superphosphate without any alkaline salts, gives smaller crops than plats 12, 13, and 14, and therefore contains less crop residue. Plats 12, 13, and 14, though utilizing more nitrogen, have more nitrates near the surface, owing probably to more active nitrification. The most interesting results, however, in this table are those showing the nitric nitrogen contained in the third and subsequent lower depths of plats 11, 12, 13, and 14.

Unfortunately there are no samples of the fourth and lower depths for plats 10a and 10b, but we have samples of eight depths for plats 11, 12, 13, and 14. As we enter the third, and more especially as we descend into the fourth and lower depths of these plats, we are at once struck with the very much larger quantity of nitrates found on plat 11, the most poorly yielding plat of the series, viz, the plat which, though receiving the same nitrogen and phosphates as the others, receives no alkalies. We find, despite the fact that we are below the level of the drainpipes in the fourth depth, 11.66 pounds of nitric nitrogen per acre in plat 11, while the other plats average only about 6 pounds. In the fifth depth plat 11 again shows us 8.60 pounds against an average of about 5 pounds in the others; in the sixth depth, 5.02 pounds, as against an average of about 4.6 pounds in the others; in the seventh depth, 4.48 pounds, as against an average of 4.7 pounds in the others; and in the eighth depth, 6.11 pounds, as against an average of nearly 5 pounds in the others. Altogether below the level of the drainage (27 inches) we have in the five depths 35.87 pounds of nitric nitrogen in plat 11 against an average of 25.44 pounds in the other plats, a difference of 10.43 pounds. This very marked difference concords with the fact that plat 11, though receiving, like the others, abundant dressings of phosphates as well as ammonium salts, receives no potassium, sodium, or magnesium salts and consequently utilizes far less of the applied nitrogen.

In fact, in the ten years from 1882 to 1891 the nitrogen annually removed in the crops of plat 11 was, on the average, 11 pounds per acre per annum less than on plats 12, 13, and 14.

When we regard plats 12, 13, and 14 we see that in their lower depths the least quantity of nitric nitrogen is in plat 13, which receives potassium salts and on which the crops, in virtue of the potash supplied, are able to assimilate more nitrogen and are consequently more luxuriant. This plat shows for the fourth to the eighth depths 19 pounds of nitric nitrogen per acre, while plats 12 and 14 show in the like depths 29 pounds and 30¾ pounds, respectively. These two latter plats received some potash dressings during the first ten years, prior to 1852, and have ever since shown greater fertility and greater nitrogen-assimilating power than plat 11. This is probably not wholly due to the survival of the effects of the early potash dressings. These two plats have since 1852 been respectively supplied with annual dressings of sodium and magnesium salts, the soil-solvent action of which has probably liberated natural soil potash. But in any case they have grown larger crops than plat 11, assimilating, therefore, more of their nitrogen supply—a fact which accords most interestingly with the smaller quantity of nitrates in their subsoils.

HOW FAR DO THE NITRATES FOUND ACCOUNT FOR NITROGEN LOST?

In Table 26 we constructed a balance account for the nitrogen supplied to various plats, the nitrogen removed in the crops, found in the surface soil, and not accounted for—the unaccounted for nitrogen being described as mainly nitrogen lost in drainage and the small quantity possibly accumulated in the subsoil. We took as a standard plat 3 (unmanured). If we reconstruct the table, taking plat 5 (minerally manured but receiving no nitrogen) as the standard, we get slightly different but equally comparable figures which are more convenient for our present purpose. The table will then be nearly on the same lines as that of Sir Henry Gilbert, given in his lectures to you (p. 156), in which he estimated the annual additions, removals, accumulations, and losses of nitrogen for the plats over a period of thirty years—1852–1881. The table was based on the results chronicled and discussed in the paper on the rain and drainage waters at Rothamsted, referred to on page 49, and included an estimate of the nitric nitrogen contained in the pipe drainage from the various plats based upon a large number of analyses, but not purporting (owing to the incompleteness of the analyses) to be more than a probably fair estimate. The earlier results were, however, supplemented by the results obtained by the analysis of the 1881 soil samples. I have endeavored, in a corresponding table, to arrive at an estimate for the longer period of fifty years, lasting from the beginning of the experiments to 1893. The figures for the accumulations of total nitrogen are based on the analyses of the 1893 samples, and the crop estimates are based on actual analyses of the produce for forty years, and on an estimate made for the crop yields of each plat for the earlier years in which analyses of the grain and straw were not made. The average annual estimates are probably correct within about 1 pound per acre. The estimates of loss by drainage, however, are adopted from Sir Henry Gilbert's former estimates.

Table 39.—*Broadbalk wheat soils, plats 10, 11, 12, 13, 14, and 7—Supply, estimated removal, accumulation, and loss of nitrogen by drainage, etc.*

	Nitrogen per acre per annum in excess of that for plat 5.				
	Added in manure.	Removed in crops.	Annually accumulated in surface soil.	Estimated loss from drain pipes.	Unaccounted for (subsoil drainage or accumulation and any other losses).
1852-1881 (30 years):	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Plat 10	86	12.4	*a* 4.8	31.2	37.6
Plat 11	86	17.7	*a* 11.6	28.5	28.2
Plat 12	86	22.2	*a* 14.6	24.5	24.7
Plat 13	86	23.4	*a* 17.8	25.6	19.2
Plat 14	86	24.1	*a* 15.5	27.5	18.9
Plat 7	86	25.9	*a* 19.3	19.0	21.8
Average	....	20.9	*a* 13.9	26.0	25.1
1843-1893 (50 years): *b*					
Plat 10a	86	8.0	*c* 3.0	31.0	44.0
Plat 10b	86	11.0	*c* 3.0	31.0	41.0
Plat 11	86	15.0	*c* 6.0	28.5	36.5
Plat 12	86	17.0	*c* 9.5	24.5	35.0
Plat 13	86	21.0	*c* 8.0	25.5	31.5
Plat 14	86	20.0	*c* 12.5	27.5	26.0
Plat 7	86	25.0	*c* 11.0	19.0	31.0
Average	....	16.7	*c* 7.6	26.7	35.0

a Soil accumulation based on analyses of 1881 samples.
b See note "*a*," Table 26, p. 49.
c Soil accumulation based on analyses of 1893 samples.

The estimated annual quantity of nitrogen in excess of plat 5, yielded in crops over the fifty years 1843–1893, as compared with the thirty years 1852–1883, is lower throughout, chiefly owing to the higher average yield of nitrogen in plat 5—namely, 24 pounds per acre per annum instead of 20.3 pounds—arrived at by including the earlier years of the experiments, when plat 5 received dressings of ammonium salts and gave far higher crops than since 1852. Then the annual soil accumulation—one-fiftieth of the difference found in 1893 in the surface soil in excess of plat 5—is less than was shown over the thirty-year period, there being necessary limits to accumulation, and the differences becoming smaller when they are reduced to average annual differences over so many years. When the estimated annual quantity unaccounted for is averaged, the fifty-year period shows, as we should expect, a greater annual loss. The chief difference is in plat 11, which has accumulated nothing on the average since 1881, while plat 5, with which it is compared, has only lost about 2 pounds per acre per annum. Indeed all the surface soils but that of plat 14 are, according to the 1893 analyses, somewhat lower in total nitrogen than in 1881, and the annual loss of nitrogen in drainage, in proportion to the nitrogen supplied, would appear to be in later years above the average estimates for the fifty years. Now, in 1881 no subsoil samples were taken below the third depth, and the conclusion that the loss unaccounted for in the pipe-drainage waters was mainly in subsoil drainage, though a fair deduction, was without means of proof. It is therefore interesting to see how far the examination of the deeper subsoils sampled in 1893 helps to corroborate the conclusion. This is seen in the following table:

TABLE 40.—*Broadbalk wheat soils, plats 10a, 10b, 11, 12, 13, 14, and 7—Estimated loss of nitrogen compared with the nitrates actually found.*

	Estimated average annual loss of nitrogen per acre in excess of plat 5 not accounted for in pipe drainage.		Nitrogen as nitrates found per acre in 1893 in excess of that in corresponding depths of plat 5.			
	1881 (30 years).	1893 (50 years).	First, second, and third depths (1 to 27 inches).	Second and third depths (9 to 27 inches).	Fourth to eighth depths (27 to 72 inches).	First to eighth depths (1 to 72 inches).
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Plat 10a	37.6 (10a and 10b)	44.0	30.1	28.1	----	----
Plat 10b		41.0	33.4	34.5	----	----
Plat 11	28.2	36.5	32.0	30.9	31.3	63.3
Plat 12	24.7	35.0	32.7	29.0	24.4	57.1
Plat 13	19.2	31.5	30.4	27.0	14.5	44.9
Plat 14	18.9	26.0	37.0	34.2	26.1	53.2
Plat 7	21.8	31.0	23.6	19.2	38.3	41.9
Average	25.1	35.0	31.3	29.0	26.9	52.1

Nitrates are shown to exist at a considerably greater depth than 72 inches. For instance, plat 7, in its ninth and tenth depths contains 8.7 pounds per acre more of nitric nitrogen. The other plats were not sampled more deeply. How long a given quantity of nitric nitrogen takes to travel down below this depth we can not say and therefore we do not know how much of the subsoil nitrates was formed within a year. But at all events, viewing the matter broadly, we seem to find existing at one time in the soil and subsoil sufficient nitrates to fairly justify the conclusion that the annual loss of ammonia is well accounted for. However, as has been already said, although ammonium salts nitrify rapidly under favorable circumstances, it is nevertheless possible, and indeed probable, that some of the ammonia of the ammonium salts applied in the very dry season of 1893 had not become nitrified at the time at which these samples were taken.

CHLORIN.

GENERAL DISCUSSION AND FULL STATEMENT OF ANALYTICAL RESULTS.

Before proceeding to further discuss the nitrogen question, we may pause a while here to consider the results of the determinations of chlorids in the various soils and subsoils, as these—being, like nitrates, soluble and migratory constituents—throw some light upon the movements of water in the soil, and are indirectly interesting in connection with the question of soil nitrates and their movements.

One point of interest in determining the amount of chlorin was as ome gauge of the migrations of soil constituents in the soil and sub-oil. The subject is also of interest inasmuch as chlorin, like sul-hurie acid and nitric acid, is responsible for the removal of lime from he soil in the form of drainage. The following table shows the chlorin xisting as chlorids found in the 1893 samples of each plat to each epth sampled. The results are stated as parts per million of fine ry soil and as pounds per acre.

TABLE 41.—*Broadbalk wheat soils, samples collected in October, 1893*—CHLORIN (*parts per million of fine dry soil*).

Plat.	Annual manuring.	Nitrogen in manure per acre per annum.	First depth.	Second depth.	Third depth.	Fourth depth.	Fifth depth.	Sixth depth.	Seventh depth.	Eighth depth.	Ninth depth.	Tenth depth.
		Pounds.	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*	*Parts.*
2a	Farmyard manure since 1884	200	9.77	9.80	8.01	......	......	......	......	......	......	......
2b	Farmyard manure 50 years	200	14.74	13.49	5.57	......	......	......	......	......	......	......
3	Unmanured	0	3.90	6.33	4.05	......	......	......	......	......	......	......
4	Unmanured since 1852	0	3.28	6.83	5.23	......	......	......	......	......	......	......
5	Full minerals	0	6.36	7.69	4.96	4.92	4.56	4.19	5.66	6.30	4.76	4.96
6	Full minerals and ammonium salts	43	5.75	10.11	6.20	6.90	7.20	7.43	7.12	6.25	6.20	6.32
7	Full minerals and ammonium salts	86	5.54	10.05	7.75	8.53	10.35	8.68	8.82	8.47	8.68	8.32
8	Full minerals and ammonium salts	129	4.91	13.10	9.28	12.42	13.94	12.73	11.25	11.55	12.10	10.91
9a	Full minerals and sodium nitrate	43	0.72	8.37	5.88	......	......	......	......	......	......	......
9b	Sodium nitrate only	43	2.47	7.20	7.88	......	......	......	......	......	......	......
10a	Ammonium salts (no minerals since 1844)	86	6.69	11.98	8.71	......	......	......	......	......	......	......
10b	Ammonium salts (no minerals since 1850)	86	1.44	11.08	9.41	......	......	......	......	......	......	......
11	Phosphates and ammonium salts	86	3.49	9.88	8.31	10.44	11.21	10.06	11.23	14.04	......	......
12	Phosphates, sodium, and ammonium salts	86	4.32	10.95	8.89	10.31	11.71	11.03	9.98	11.28	......	......
13	Phosphates, potassium, and ammonium salts	86	5.25	16.60	8.30	10.97	9.70	10.08	10.75	9.87	......	......
14	Phosphates, magnesium, and ammonium salts	86	3.82	13.04	10.43	8.98	10.56	9.75	10.34	10.62	......	......
15	Full minerals and ammonium salts (autumn)	86	2.88	11.74	13.34	11.84	10.83	11.23	9.81	11.36	......	......
16	Full minerals and sodium nitrate since 1884	86	2.57	7.18	7.12	4.43	5.25	4.49	6.10	5.15	......	......
17	Full minerals and ammonium salts transposed in alternate years	*a* 86	2.46	7.75	7.76	8.81	9.40	8.11	7.66	6.31	......	......
18			4.00	13.32	9.13	6.11	7.35	6.10	5.63	5.48	......	......
19	Rape cake	93	4.52	7.46	12.45	......	......	......	......	......	......	......

a Plat 18 received the 86 pounds nitrogen in the form of ammonium salts for the crop of 1893.

TABLE 42.—*Broadbalk wheat soils, samples collected in October, 1893*—CHLORIN (*pounds per acre in soils and subsoils*).

Plat.	Annual manuring.	Nitrogen in manure per acre per annum.	First 9 inches.	Second 9 inches.	Third 9 inches.	Fourth 9 inches.	Fifth 9 inches.	Sixth 9 inches.	Seventh 9 inches.	Eighth 9 inches.	Ninth 9 inches.	Tenth 9 inches.	Summary. First to third 9 inches.	Summary. First to eighth 9 inches.	Summary. Ninth and tenth 9 inches.	Summary. First to tenth 9 inches.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
2a	Farmyard manure since 1884	200	24.52	26.18	22.36	....	....	....	....	....	....	....	73.06	....	....	....
3b	Farmyard manure 50 years	200	34.30	36.04	15.55	....	....	....	....	....	....	....	85.99	....	....	....
3	Unmanured	0	10.11	16.91	11.31	....	....	....	....	....	....	....	38.33	....	....	....
4	Unmanured since 1852	0	8.50	18.25	14.60	....	....	....	....	....	....	....	41.35	....	....	....
5	Full minerals	0	16.49	20.54	13.85	13.69	13.07	11.89	16.15	18.07	14.30	14.89	50.88	123.75	29.19	152.94
6	Full minerals and ammonium salts	43	14.91	27.01	17.31	19.21	20.63	21.08	20.31	17.93	18.62	18.97	59.23	158.39	37.59	195.98
7	Full minerals and ammonium salts	86	14.36	26.85	21.63	23.74	29.66	24.62	25.16	24.29	26.07	24.97	62.84	190.31	51.04	241.35
8	Full minerals and ammonium salts	129	12.73	34.99	25.91	34.57	30.95	36.11	32.09	33.13	36.34	32.75	73.63	249.48	69.09	318.57
9a	Full minerals and sodium nitrate	43	1.87	22.36	16.41	....	....	....	....	....	....	....	40.64	....	....	....
9b	Sodium nitrate only	43	6.40	19.23	22.00	....	....	....	....	....	....	....	47.63	....	....	....
10a	Ammonium salts (no minerals since 1844)	86	17.34	32.00	24.31	....	....	....	....	....	....	....	73.65	....	....	....
10b	Ammonium salts (no minerals since 1850)	86	3.73	29.60	26.27	....	....	....	....	....	....	....	59.60	....	....	....
11	Phosphates and ammonium salts	86	9.05	26.39	23.20	29.06	32.12	28.54	32.03	40.27	....	....	58.64	220.66	....	....
12	Phosphates, sodium, and ammonium salts	86	11.20	29.25	24.82	28.70	33.56	31.29	28.47	32.35	....	....	65.27	219.64	....	....
13	Phosphates, potassium, and ammonium salts	86	13.61	44.34	23.17	30.53	27.80	28.60	30.67	28.31	....	....	81.12	227.03	....	....
14	Phosphates, magnesium, and ammonium salts	86	9.90	34.83	29.12	25.00	30.26	27.66	29.50	30.46	....	....	73.85	216.73	....	....
15	Full minerals and ammonium salts (autumn)	86	7.47	31.36	37.24	32.96	31.03	31.86	27.98	32.58	....	....	76.07	232.48	....	....
16	Full minerals and sodium nitrate since 1884	86	6.66	19.18	19.88	12.33	15.04	12.74	17.40	14.77	....	....	45.72	118.00	....	....
17	Full minerals and ammonium salts transposed in alternate years	*a* 86	6.38	20.70	21.66	24.52	26.94	23.01	21.85	18.10	....	....	48.74	163.16	....	....
18			10.37	35.58	25.49	17.01	21.06	17.31	16.06	15.72	....	....	71.44	158.60	....	....
19	Rape cake	93	11.66	19.93	34.75	....	....	....	....	....	....	....	66.34	....	....	....

a Plat 18 received the 86 pounds nitrogen in the form of ammonium salts for the crop of 1893.

You may be reminded that a large quantity of chlorin is supplied to many of these soils in the form of ammonium chlorid, for, in every case in which ammonium salts are used they consist half of ammonium sulphate and half of ammonium chlorid. Of the chemically manured plats, plat 5 alone receives, intentionally, no chlorin, but a small quantity is introduced as impurities in the other commercial saline matters used as mineral dressings. Thus we notice that there is more chlorin in the upper depths of plat 5 than in the corresponding depths of plat 3 or plat 4, which receive nothing but the chlorin which annually finds its way into the land in rain. In the dunged plats, down to the third depth, we find on the average about twice as much chlorin as in the unmanured plats.

The plats manured with ammonium salts are, as we should expect, richer in chlorin than the plats not so manured, though the quantity found in the surface soils is, as a rule, smaller than we might expect, owing, no doubt, to washing down from the surface soils into the lower depths during the rains between harvest and the time of collecting the soil samples.

The quantity of chlorin contained in the lower depths of the plats, the sampling of which has been carried down deeply, especially of plat 5—which receives no chlorids except as impurities in its mineral manures—is far higher than would have been expected. The total quantity of chlorin contained, from the surface to the tenth depth (90 inches), is nearly 153 pounds per acre, or 15.29 pounds per acre, on the average, for each depth of 9 inches. On the whole, too, this quantity is fairly uniformly distributed.

Now, the average quantity of chlorin which falls annually in the rainfall at Rothamsted, as calculated on observations for twenty-two harvest years, 1877–78 to 1898–99, was 14.75 pounds. Observations made on the waters running through the soil drain gauges during the same time have shown that the chlorin in the drainage from the gauge containing 20 inches of soil has averaged 14.20 pounds per annum; that in the water from the gauge containing 40 inches of soil, 15.28 pounds; and that in the water from the gauge containing 60 inches of soil, 13.90 pounds, the average of the three being 14.46 pounds per annum—that is to say, the average annual quantity of chlorin contained in the water flowing from the soil drain gauges is almost exactly equal to the average annual quantity coming down in rain. Yet we see that the soil of plat 5 in the Broadbalk wheat field retains, on the average, within each depth of 9 inches down as far as 90 inches, a quantity of chlorin equivalent to that which falls upon its surface each year in the form of rain. In other words, down to a depth of 90 inches the soil, though continually subjected to the washing influence of the rain, contains a quantity of chlorids equivalent to that which falls upon it during ten years, neglecting the very few pounds annually supplied to it as impurities in the manures.

When we examine the figures for the plats actually receiving chlorids, very interesting differences are found. Where 43 pounds of nitrogen per acre is annually supplied as ammonium salts (half as chlorid), as on plat 6, 56 pounds of chlorin will be included in the dressing. On the various plats receiving 86 pounds of nitrogen per acre as ammonium salts, the annual quantity of chlorin included is 112 pounds, and where 129 pounds of nitrogen per acre is supplied, as on plat 8, 168 pounds of chlorin are included in the dressing.

If we compare the figures relating to plats 5, 6, 7, and 8, we see that, though there is practically little difference in the first 9 inches, there is, if we take the second and third depths, more chlorin in the soil the more there has been applied in manure, though the difference is not precisely proportional; and in the lower (fourth to tenth) depths there is, in every case but one, more chlorin found in the soil of plat 6 than in that of plat 5, more in that of plat 7 than in that of plat 6, and more in that of plat 8 than in that of plat 7. Taking into account the total depth of 90 inches, the chlorin found in plat 5 amounts to 152.94 pounds per acre; that in plat 6 to 195.98 pounds; that in plat 7 to 241.35 pounds; and that in plat 8 to 318.57 pounds. Plats 6, 7, and 8, therefore contain in their ten depths, in round numbers, respectively, 43 pounds, 88 pounds, and 165 pounds in excess of what we find in plat 5, numbers which bear on the whole a striking resemblance to the quantities of chlorin contained in the ammonium salts supplied to each plat—namely, 56 pounds, 112 pounds, and 168 pounds, respectively. We therefore find, retained in the total ten depths of 9 inches each, the chlorin of ten years' rainfall, and in addition approximately that of one year's application of ammonium salts. The chalk is not far below these ten depths, and there will doubtless be a large annual loss by drainage carrying off bases from the soil combined, among other forms, as chlorids. It is certainly very remarkable to find that a constituent whose salts are so soluble as those of chlorin should be retained to so great an extent in the soil, or that the amount retained should bear such obvious relation to the annual sources of supply. It would seem that the clay enters into some sort of combination with the chlorids from which they are only dislodged by a very free application of water.

The difficulty of removing chlorids from soil by percolation, except when a relatively very large quantity of water was used, was demonstrated in some experiments described in the paper on the rain and drainage waters at Rothamsted, referred to on p. 49.

Referring to the results recorded for plats 11, 12, 13, and 14, where the same quantity of ammonium salts is applied annually with different mineral manures, it is seen that the total retention of chlorin, down to 8 times 9 inches, varies but very little, though considerable variations are found in the first 3 depths.

Comparing plats 15 and 16, the former of which receives ammonium salts every year containing 112 pounds of chlorin per acre, the latter having received for ten years the same quantity of nitrogen as plat 15, but in the form of sodium nitrate, we find the quantities of chlorin contained in the eight depths examined to be, respectively, in round numbers, 232 pounds and 118 pounds per acre; the difference of 114 pounds being almost exactly the quantity of chlorin contained in a year's application of ammonium salts. On the sodium nitrate plat the quantity of chlorin is almost the same as on plat 5, without ammonium salts.

It will be noticed throughout that below the first two or three depths there is comparative uniformity in the quantity of chlorin found from depth to depth in each plat, and the differences are probably due to more or less of absorbent clayey matter, with corresponding variations to the quantity of sand or gravel which, when in excess would tend to aid, and when in deficiency to retard, percolation.

CHLORIN IN CROPS.

It is interesting here to see the quantities of chlorin contained in the crops produced on the various plats. The following table (Table 43) shows this for some of the plats over a period of forty seasons, namely, from 1852 to 1891. The chlorin, it should be observed, is mainly found in the straw as part of the miscellaneous unassimilated matters of the stems and leaf, the quantity in the grain itself being comparatively trifling.

TABLE 43.—*Broadbalk wheat plats*—CHLORIN *per acre removed per annum in total produce (grain and straw).*

	Plat 2b, farmyard manure.	Plat 3, unmanured.	Plat 5, minerals only.	Plat 7, full minerals and ammonium salts.	Plat 10a, ammonium salts only.	Plat 10b, ammonium salts only.	Plat 11, phosphates and ammonium salts.	Plat 12, phosphates, sodium, and ammonium salts.	Plat 13, phosphates, potassium, and ammonium salts.	Plat 14, phosphates, magnesium, and ammonium salts.
Chlorin in grain and straw per acre:										
Average of 10 years—	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1852–1861	6.78	1.71	2.59	8.52	3.32	4.10	3.59	6.05	8.27	7.54
1862–1871	7.26	1.58	2.12	9.33	2.79	3.70	4.65	5.74	9.81	6.00
1872–1881	3.50	.82	1.17	7.03	1.24	1.38	1.83	3.04	6.58	3.19
1882–1891	7.75	1.15	1.46	12.25	2.26	2.64	1.87	4.19	9.69	4.06
Average	6.32	1.32	1.84	9.28	2.40	2.96	2.99	4.76	8.59	5.20
Total produce per acre (grain and straw):										
42 years' average	5,755	1,934	2,242	5,629	3,104	3,501	3,988	4,973	5,365	5,112
Chlorin per 1,000 pounds of produce (grain and straw), average	1.09	0.68	0.82	1.65	0.77	0.85	0.75	0.96	1.60	1.01

It is evident from the results given in this table that a high proportion of chlorin in the crops is not merely related to an abundant supply of chlorin in manure. For instance, the produce of plat 5, which receives no chlorids, contains, in relation to its weight, no less chlorin than that of plats 10 and 11, receiving ammonium chlorid (and sulphate) with and without phosphates. The quantity of chlorin contained in the produce of plat 12, to which sodium sulphate is applied in addition to the ammonium chlorid, ammonium sulphate, and superphosphate, is, in relation to its weight, a little—but not much—higher, and still a little higher in the case of the dunged plat. But all these plats, with the exception of 7 and 13, show a ratio of chlorin to produce comprised within a range of from 0.68 (unmanured plat) to 1.09 (dunged plat) per 1,000 pounds of grain and straw. But on plats 7 and 13, the plats which, in addition to ammonium salts and superphosphate, receive potassium sulphate, the ratios of chlorin to produce are 1.65 and 1.60, respectively, per 1,000 pounds of produce. These two plats are the healthiest, most flourishing, and most abundantly yielding of all the chemically manured plats, as has been already more than once pointed out; and their prosperous condition is without doubt the direct result of the potash supplied to them. But the dunged plat is also a prosperous plat, and yields heavier crops than these; yet the chlorin contained in a given weight of its produce is much less than in the case of plats 7 and 13. The presence of the increased quantity of chlorin in the crops, therefore, can not be regarded as merely a necessary index of well-being or of vigorous growth.

The high ratio of chlorin to produce on plats 7 and 13 can not be attributed to accident. Not only are the plats far apart on the field, but their altogether exceptional chlorin contents are deduced from analyses of the ashes ranging over forty years, and the high chlorin results in the crops of both plats are persistently shown in each ten years' average.

Chlorin is applied to the soil in the form of ammonium chlorid; but this form we know, of course, it can not retain, for its ammonia is converted into nitrates, and the chlorin must combine with other bases, the most obvious being calcium. It seems possible that the calcium chlorid first formed may to some extent decompose the potassium sulphate present on these plats, forming potassium chlorid, and that potassium chlorid may be more freely taken up by the plants than sodium chlorid. It is true that plat 13 was found, in the 1893 soil sample, to contain in its second depth a much larger quantity of chlorin than its neighbors—plats 11, 12, and 14; but this was not noticed to be the case with plat 7.

We have records of the potash contained in the crops over the same period, and from these it appears that increase in the potash contained in the crops per acre is in every case accompanied by an increase in the chlorin contained in the crops; and if, instead of regarding the quantities per acre, we regard the quantities contained per 1,000 pounds of produce, and take the plats that are strictly comparable (e. g., plats 11, 12, 13, 14, and 7), including also plat 2, we find that increase of potash for a given weight of crop is accompanied by increase of chlorin. This is seen in the following table:

TABLE 44.—*Broadbalk wheat soils—Potash and chlorin in crops on various plats.*

	Plat 3, unmanured.	Plat 5, minerals only.	Plat 10a, ammonium salts only.	Plat 10b, ammonium salts only.	Plat 11, phosphates and ammonium salts.	Plat 12, phosphates, sodium, and ammonium salts.	Plat 14, phosphates, magnesium, and ammonium salts.	Plat 2, farmyard manure.	Plat 13, phosphates, potassium, and ammonium salts.	Plat 7, full minerals and ammonium salts.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Potash per acre in produce, annually, over 40 years	14.29	19.91	20.37	23.07	23.35	35.01	36.80	50	51.57	53.06
Chlorin per acre in produce, annually, over 40 years	1.32	1.84	2.40	2.96	2.99	4.76	5.20	6.30	8.59	9.28
Potash contained in 1,000 pounds of average produce (grain and straw) annually	------	------	------	------	5.85	7.04	7.20	8.97	9.32	9.40
Chlorin contained in 1,000 pounds of average produce (grain and straw) annually	------	------	------	------	.75	.96	1.01	1.09	1.60	1.65

ACTION OF AMMONIUM SALTS ON THE LIME OF THE SOIL.

A paper "On the composition of waters of land drainage," by the late Dr. Augustus Voelcker, F. R. S.,[1] gives the detailed results of the examination of a large number of samples of drainage water collected from the Broadbalk field and supplied to him for the purpose by Messrs. Lawes and Gilbert in the years 1866, 1867, 1868, and 1869. These results are the only ones in existence giving complete analyses of the mineral constituents of these drainage waters; and the results of Dr. Voelcker's analyses are summarized and expressed as parts per million in the Rothamsted paper "On the amount and composition of the rain and drainage waters collected at Rothamsted," already several times referred to. (See p. 49.) The results of the mean analyses are given as follows:

[1] Journal of the Royal Agricultural Society of England, 2. ser., 10 (1874), pp. 132–165.

TABLE 45.—*Broadbalk wheat plats—Composition of drainage waters, in parts per million; samples collected in 1866, 1867, 1868, and 1869 (Dr. Augustus Voelcker's analyses).*

[Results of mean analyses.]

	Total solid matter.	Lime.	Magnesia.	Potash.	Soda.	Nitrogen as—		Chlorin.	Sulphuric acid.	Phosphoric acid.
						Ammonia.	Nitric acid.			
Plat 2	476.1	147.4	4.9	5.4	13.7	0.16	16.1	20.7	106.1	......
Plat 3 and 4	246.4	98.1	5.1	1.7	6.0	.12	3.9	10.7	24.7	0.63
Plat 5	326.0	124.3	6.4	5.4	11.7	.13	5.1	11.1	66.3	.91
Plat 6	407.6	143.9	7.9	4.4	10.7	.20	8.5	20.7	73.3	1.54
Plat 7	492.4	181.4	8.3	2.9	10.9	.07	14.0	26.1	90.1	.91
Plat 8	548.4	197.3	8.9	2.7	10.6	.27	16.9	39.4	89.7	.17
Plat 9	423.9	118.1	5.9	4.1	56.1	.24	18.4	12.0	41.0	....
Plat 10	406.9	154.1	7.4	1.9	7.1	.08	13.9	32.0	44.4	1.44
Plat 11	425.9	165.6	7.3	1.0	6.6	.17	15.3	31.6	54.3	1.66
Plat 12	530.9	191.6	6.6	2.7	24.6	.30	15.1	30.9	96.7	1.26
Plat 13	544.3	201.4	9.3	3.3	6.1	.16	17.4	36.6	86.9	1.09
Plat 14	598.6	226.7	11.6	1.0	5.6	.09	19.2	39.4	99.7	1.01
Plat 15	585.3	201.1	7.9	5.3	14.3	.11	24.2	24.6	123.9	1.54
Plat 16[a]	286.7	117.1	5.3	2.4	5.1	.09	7.0	11.4	21.9	.91

[a] Then unmanured.

A careful study of these results clearly indicates that increase in nitric acid, increase in sulphuric acid, and increase in chlorin are accompanied by a very marked increase in lime. In most cases the increase in soda or magnesia is comparatively small, while there is, on the whole, less of potash than of any other base, and very little fluctuation in its quantity. The ammonium sulphate and ammonium chlorid, as you have already been reminded, are potentially, as regards the bases of the soil, to be looked upon as though they consisted of hydrochloric, sulphuric, and nitric acid, since their nitrification can be carried out only in the presence of a supply of alkaline bases, which combine with the sulphuric acid and chlorin originally present, and are also contained, in combination with nitric acid, in the nitrates formed from the ammonia. The nitrates are of course to some extent taken up by the growing crops; but the nitric nitrogen that passes away in the drainage, like the sulphuric acid and the chlorin, must take away with it an equivalent quantity of base, the principal base present in the drainage waters being lime.

The drainage waters from the plats manured with ammonium salts contain, on the average, about 185 parts of lime per million. In round numbers, this would equal per acre for 10 inches percolation of drainage water about 400 pounds of lime per annum.

On the plats unmanured, or manured with minerals only (plats 3, 4, 5, and 16), the average is 339 parts of lime per million, equal, on the same basis of calculation, to only about, in round numbers, 250 pounds per acre per annum in 10 inches of drainage percolation.

It is interesting to compare with the ammonia plats plat 9, which at that time received every year 550 pounds of sodium nitrate per acre. The drainage water from this plat contained only 118 parts per million of lime equal, in 10 inches percolation, to 265 pounds per acre per annum, or only about the same quantity as was found in the drainage of the plats receiving no nitrogenous manure.

There was found in the drainage water from the sodium-nitrate plat a much larger quantity of soda than in the drainage from the other plats, the excess being more than sufficient to combine with the nitric acid present. It is often, and apparently without justification, stated that nitrate of soda robs the soil of lime, on the ground that the unused excess which passes away in the drainage water passes away as calcium nitrate. But, on the Rothamsted soils at all events, which are naturally abundantly supplied with lime, such does not appear to be the case. It is, on the contrary, the ammonium salts which behave nefariously as regards the lime of the soil, and therefore it appears inadvisable in practical agriculture to use ammonium salts in place of nitrate of soda, except on soils which contain a fair quantity of lime. If ammonium salts are used persistently on soils poor in lime, care must be taken to restore lime from time to time to guard against this form of loss.

The impoverishment of the surface soil in lime under the continued application of large quantities of ammonium salts appears to be indicated by the following analyses which, at the suggestion of Sir John Lawes, I recently made of some of the 1893 samples of the Broadbalk soils in my possession:

TABLE 46.—*Broadbalk wheat soils, samples collected in October, 1893—Lime in soils and subsoils.*

Depth.	Plat 3, continuously unmanured.		Plat 5, full mineral manures; no ammonium salts.		Plat 7, full mineral manures, with 400 pounds ammonium salts per acre per annum.	
	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
First (1 to 9 inches)	2.464	63,881	2.766	71,711	2.060	53,407
Second (10 to 18 inches)	.481	12,849	.683	18,245	.739	19,741
Third (19 to 27 inches)	.638	17,820	.582	16,246	.694	19,373

Both plat 5 and plat 7 receive a considerable yearly supply of sulphate of lime in the form of superphosphate. Plat 5, as we should expect, is much richer in lime in the first and second depths than the unmanured plat; but plat 7, which receives annually ammonium salts as well as superphosphate, is in the surface soil far poorer.

The difference in lime between the surface soils of plats 5 and 7 is no less than 18,304 pounds per acre. The lime supplied to both plats in manure has been the same in quantity; and if the soils originally contained like proportions of lime, the loss of lime to the surface soil owing to the ammonium salts has been about 360 pounds per acre per annum.

The foregoing digression followed on the consideration of the chlorin results, which, as dealing with water-soluble constituents, appeared related to the water-soluble nitrates.

GENERAL COMPARISON OF THE QUANTITY OF TOTAL NITROGEN PER ACRE IN THE ROTHAMSTED SOILS AND SUBSOILS WITH THE QUANTITY ANNUALLY AVAILABLE OR UTILIZED WHEN NONE IS SUPPLIED BY MANURE.

Plat 5 on the Broadbalk wheat field, continuously manured with minerals, but receiving no manurial nitrogen, and at present in a state of starvation for lack of a sufficient supply of nitrogen in an assimilable form, nevertheless contains, in round numbers, in the first 27 inches 6,401 pounds (or nearly 3 tons) of nitrogen per acre. We remarked that, notwithstanding this large quantity of nitrogen, experience teaches that a small top-dressing of sodium nitrate or of ammonium salts would in a single season convert the poor yield of this plat from 14¾ bushels of wheat, with 10¼ hundredweight of stunted straw per acre, into a rich crop of probably 35 bushels of wheat with a luxuriant growth of straw. We observed, then, that nature was but niggardly in her annual doles from the great store of total nitrogen naturally contained in her surface soils, and we asked, "What does she spare us, and how?" At that point we turned aside to examine the question of the nitric nitrogen contents of the field as revealed by the latest series of analyses, and we may now return to the former question.

By the consideration of various Rothamsted results an attempt has been made to estimate the quantity of nitrogen annually rendered available by natural means for plant food on soils either unmanured or manured with mineral dressings only. The plats selected for examination have been plats 3 and 5 of the Broadbalk field, examined separately and in different ways in the light of the analyses of the 1881 and 1893 samples; the unmanured plat (plat 3) of the grass land of the park, with its mixed herbage (estimate for forty years); the unmanured continuous root-crop plats in Barn field (estimate for thirty-six years); and the unmanured plats and superphosphate plats, representing seven courses (twenty-eight years) of four-course crop rotations in Agdell field. We have also the results obtained by the constant analyses (over twenty years) of the waters running from the fallow-soil drain gauges.

BROADBALK FIELD.

The first results to be referred to relate to the produce of wheat over thirty years in Broadbalk field, firstly, on plat 3 without manure, and, secondly, on plat 5, with mineral manure only.

TABLE 47.—*Broadbalk wheat field, plats 3 and 5*—NITROGEN *per acre per annum in crops and drainage.*

	Plat 3.	Plat 5.
	Pounds.	*Pounds.*
Nitrogen contained in crops 30 years (1851-52 to 1880-81)	18.6	20.3
Estimated loss in drainage (assumed 27 inches)	10.3	12.0
Total	28.9	32.3
Nitrogen derived from rain, dew, etc. (estimated)	5.0	5.0
Difference	23.9	27.3

On plat 3, without manure, the average yield of nitrogen per acre in the crops was 18.6 pounds per annum, and the estimated quantity in the drainage water, to a depth of 27 inches, was 10.3 pounds, giving a total of 28.9 pounds in crops and drainage.

On plat 5 the quantity of nitrogen contained in the crops was, on the average, 20.3 pounds, and the estimated quantity in the drainage 12 pounds, giving a total of 32.3 pounds per acre per annum in crops and drainage.

The quantity of nitrogen estimated to be contained in the average annual rainfall, and in minor aqueous deposits, such as dew, at Rothamsted, is 5 pounds per acre. If this be deducted in each case, we have an average net yield of soil nitrogen of 23.9 pounds and 27.3 pounds, respectively, for the two plats.

The next results, shown in the following table, also relate to the Broadbalk wheat field, and indicate the quantity of nitrogen in the form of nitrates (or "nitric" nitrogen) found in the soils of plats 3 and 5 to a depth of 27 inches, and, on plat 5, also the quantity found in a depth of 90 inches.

TABLE 48.—*Broadbalk wheat soils (1893)*—NITROGEN *as* NITRATES (*"nitric" nitrogen*) *in plats 3 and 5.*

	Soil 27 inches deep.		Soil 90 inches deep. Plat 5.
	Plat 3.	Plat 5.	
	Pounds.	*Pounds.*	*Pounds.*
Nitrogen found in soil as nitrates	21.60	19.12	25.17
Deduct nitrogen derived from rain, dew, etc. (estimated)	5.00	5.00	5.00
Difference	16.60	14.12	20.17
Add nitrogen contained in crops, 30 years (1851-52 to 1880-81)	18.60	20.30	20.30
Total	35.20	34.42	40.47

It will be seen that when the 5 pounds per acre per annum for the nitrogen of the rainfall, etc., are deducted, and the quantity added which is estimated to be contained in the crops (for which in this case the thirty years' estimate to 1881 is adopted), we obtain results differing from the previous ones in so far as we have substituted for the estimate of nitrogen removed in the pipe drainage the actual quantity of nitrogen found unused in the autumn to the depth in two cases of 27 inches and in one case of 90 inches. From these latter estimates we find for plats 3 and 5, 35.20 pounds and 34.42 pounds per acre, respectively, of nitric nitrogen contained in the first 27 inches. But if on plat 5 we include the nitrates found in the lower depths, we get about 6 pounds more, viz, 40.47 pounds per acre per annum.

No allowance is made for the nitric nitrogen temporarily stored as roots, stubble, and weed residue, which for the moment are regarded as part of the soil.

GRASS LAND.

Next we have the results calculated from observations made on the grass land of the park with its mixed herbage, the plat taken for examination being the unmanured plat, plat 3. These results are given in the following short table:

TABLE 49.—*The park, Rothamsted—Grass land (mixed herbage), plat 3 (unmanured).*

		Pounds per acre.
Nitrogen contained in crops, first twenty years (1856–75), first crops only		33.0
Nitrogen derived from rain, dew, etc. (estimated)		5.0
Difference		28.0
Nitrogen contained in crops, second twenty years (1876–95)	1st crops	26.0
	2d crops	13.2
Total		39.2
Deduct nitrogen derived from rain, dew, etc		5.0
Difference		34.2

During the first twenty years, in which the first crops only were removed from the land, the annual removal of nitrogen in hay was 33 pounds per acre; of this 5 pounds annually is estimated to have been supplied by rain, etc., leaving 28 pounds removed in the crops.

During the second twenty years, 1876–1895, both the first and second cuttings were converted into hay and removed, involving a total removal of nitrogen of 39.2 pounds per annum—leaving, after deducting the 5 pounds supplied by rainfall, a removal of 34.2 pounds of soil nitrogen.

It is to be borne in mind that the mixed herbage contains a certain proportion of leguminous vegetation, and that, in virtue of the presence of this, some amount of fixation of free nitrogen would continuously go on, which would reduce to some extent the quantities otherwise assumed as derived from the soil itself.

ROOT-CROP SOILS.

The results recorded for the root crops in Barn field are as follows:

TABLE 50.—*Root crops (Barn field), with mineral manure.*

	Pounds per acre.
Nitrogen contained in crops, 36 years (1845–1880)	25.2
Nitrogen derived from rain, dew, etc. (estimated)	5.0
Difference	20.2

The root crops with mineral manure, but without nitrogen, gave, on an average of thirty-six years, 25.2 pounds of nitrogen per acre in the crops, or, allowing for the 5 pounds contributed by rain, 20.2 pounds per acre per annum.

ROTATION LAND.

The quantities of nitrogen contained in the crops on the two plats selected for examination, on an average of the seven courses from 1848 to 1875, are as follows:

TABLE 51.—*Rotation land (Agdell field).*

	Unmanured.	Superphosphate.
	Pounds per acre.	*Pounds per acre.*
Nitrogen contained in crops (7 courses, 1848–1875)	36.8	45.2
Nitrogen derived from rain, dew, etc. (estimated)	5.0	5.0
Difference	31.8	40.2

The average annual yield of nitrogen per acre in the crops was 36.8 pounds on the unmanured plat, and 45.2 pounds on the plat manured with superphosphate. After deducting from each of these quantities 5 pounds for rainfall nitrogen, we have a soil removal of 31.8 and 40.2 pounds per acre per annum, respectively.

In no case, however, except in the wheat field, is loss by subsoil drainage taken into account; and it is to be noted that, on the rotation land, a certain proportion of the nitrogen yielded would be due to fixation of atmospheric nitrogen by the leguminous crops of the rotation, which would be more in the case of the superphosphate than in that of the unmanured plat. It is to be admitted, of course, that no one of the illustrations given affords exact evidence as to the amount of nitrogen actually available from the resources of the soil. Each illustration that we have given must be judged according to its conditions.

RAIN AND DRAINAGE (BARN FIELD).

If we examine the results (shown in the table below) yielded by the 60-inch drain gauge, which is kept fallow, we find that, deducting for rainfall, about 29 pounds of nitrogen have been collected annually per acre in the drainage. But it is to be remembered that as there are no crops there is no conservation of nitrogen in root and stubble residue, nor are any weeds allowed to grow on the soil.

TABLE 52.—*Barn field* (*rain and drainage*).

	Pounds per acre.
Nitrogen contained in drainage from 60-inch gauge (average of 20 harvest years, 1877–78 to 1896–97)	33.87
Nitrogen derived from rain, dew, etc	5.00
Difference	28.87

The wheat crops, together with the estimated loss in drainage down to 27 inches, show 24 pounds without manure and 27.3 pounds with mineral manure; and the question is, whether there is any further loss by drainage below 27 inches. Taking into account the nitrogen in the crops and that found in the soil as nitrates down to 27 inches, the quantity has been seen to be 35.2 pounds without manure and 34.42 pounds with mineral manure; or, taking the total quantity of nitrogen as nitrates down to 90 inches of depth, the quantity included in the wheat crop with mineral manure is 40.47 pounds per acre per annum. Obviously, as we have already observed elsewhere, the whole of the nitric nitrogen found to any given depth at any one time can not be taken as directly representing the annual accumulation, and so far these results may be too high.

Then the results for the mixed herbage of the grass land, including a small amount of fixation by the leguminous crops, show 28 pounds and 34.2 pounds. The root crops, with mineral manure alone, show only 20.2 pounds. And lastly, the rotation crops—including some Leguminosæ—have yielded 31.8 and 40.2 pounds. It is, however, to be again observed that no loss by drainage is brought into account in the case of either the mixed herbage, the root crops, or the rotation land. In the case of the mixed herbage, comprising a great variety of plants with widely varying root habit and root range, and more or less vegetation almost all the year round, there would probably be comparatively little loss by drainage. With land devoted to root crops there would be much more. Land under rotation, on the other hand, would certainly lose less than land under a continuous cereal crop, like that of the Broadbalk field; though it would lose more than permanent grass land.

Taking into consideration, therefore, the conditions under which the various results have been obtained, we are probably fairly justified in drawing the conclusion that, even under the most favorable conditions of mineral manuring, without manurial nitrogenous supply, the quantity of nitrogen naturally available from the enormous stores found in the Rothamsted soil and subsoil is, on the average, only about, or not much more than 30 pounds per acre per annum. Forty pounds would probably be an extravagant estimate.

CONTINUOUS WHEAT GROWING IN RELATION TO ECONOMY OF NITROGEN.

Altogether, the study of the nitrogen results indicates that continuous wheat growing is, from a natural point of view, an extravagant mode of farming, only justifiable, like other extravagances, under the pressure of a more or less artificial environment. For the wheat crop has completed its growth and is harvested long before nitrification has ceased in the soil, and there is no crop to take up either the balance of the nitrates left unused by the wheat or the larger balance formed after the active growth of the wheat is over; and these nitrates must pass away in subsoil drainage during the winter, except where the rainfall is small, or in those latitudes exposed to long winter frosts. This drainage, even on unmanured land, involves a serious loss of nitrogen, and a still greater loss when the yield of the crops is artificially increased by the use of nitrogenous manure. Ordinary rotation farming tends, far more than continuous wheat growing, to conserve the natural nitrogen of the soil, and is the sounder method of farming where local circumstances create and maintain a demand for other produce than grain—as, for instance, in any country that is fairly closely populated. But even rotation farming, with its fallows, involves a waste of nitrogen owing to its fallow intervals, except in intensive farming, where catch crops, like Trifolium or vetches, can be grown—crops which absorb the nitrates of the soil and also add, as we know, to the stock of soil nitrogen. But in continuous wheat growing this can not be done. If winter wheat is sown, there is but a short interval between harvest and seed-time in which to clean the land and prepare a seed bed. It is only where spring wheat is grown that a fallow crop becomes possible without loss of a season; and in wheat culture on a large scale it would often be a question even then between the relative economy of conserving nitrogen or utilizing the fallow time for the destruction of weeds. It is, of course, in any case, only in mild and genial latitudes with a favorable rainfall that autumn catch crops can be satisfactorily raised. If circumstances allow them to grow well and luxuriantly, they will often smother weeds and extirpate them as effectually as will more direct cleansing operations; but a poor, thin catch crop will often only encourage the growth of weeds.

In any case, however, in continuous wheat growing without rotations involving leguminous crops, we must annually lose some nitrogen, and if we are to increase, or even to maintain, the fertility of the land, we must sooner or later buy nitrogen, either directly or indirectly, in the market; and, it may be added, we must waste a good deal of it. But we have seen that the capital of soil nitrogen is very large, and that it is doled out to us so slowly and sparingly that, on originally good and fertile land, it lasts a long time, despite its annual diminution. Under some circumstances the diminution may be hastened, while in other circumstances it may be retarded by the use of mineral fertilizers, which, happily, are cheap as well as abundant. But on almost any land, when the element of rent or the saving of mere land area becomes an object, as well as the saving of labor, the time must come sooner or later when continuous wheat growing can not be conducted on primitive methods. First comes improved cultivation, then the use of mineral fertilizers, and next the use of external supplies of nitrogen. With such aid, however, continuous wheat growing can be carried on probably forever, on any reasonably good and well-conditioned soil, provided that weeds can be kept under. But only a portion of the purchased nitrogen returns to us in the produce, and we must add more than the crop requires or can assimilate, if the land is to give its best and most abundant yield. The balance is lost.

In ultimate economics there must be, therefore, agriculturally, a waste of nitrogen in continuous wheat growing, and the more highly we farm the greater the waste. But there may be in agriculture, as in many other matters, an immediate economical advantage in an ultimate economic waste. The wheat grower, very naturally, does not consider a far remote posterity, but considers the most profitable way of producing his crop for the present and in the reasonably near future. A settler in a new country first plows up a section of prairie with its accumulated nitrogenous fertility, and he grows wheat on it till nature, liberal at first, becomes parsimonious. Then he has to cultivate better and keep his ground cleaner, and after a time he has to invest a small quantity of capital in phosphates, and perhaps in potash salts, and after a further time some nitrogen also must be purchased; and the question becomes, How much and in what form can it best be bought? In crowded countries or States, where a demand is near at hand, not only for wheat, but for meat and milk and hides and horses and wool and vegetables, rotation farming and grazing soon supersede continuous wheat growing and combine to conserve natural fertility. I have been somewhat surprised to learn how largely even the most intensive form of farming, involving the systematic growth of catch crops on what would once have been fallows, has already become established in some of the Eastern States of America. At the same time the reliance on mere rotation of crops and the incidental farming operations thereby entailed, without help from purchased manures or (which is a form of the same thing) purchased food, necessarily restricts the work of the farmer and limits the quantity and nature of the material he sells. The difficulty of conserving the fertility of the soil otherwise than by rotation farming before the days of purchased farm foods and purchased fertilizers was such that, as many of you may know, the rotations of crops were laid down for English farmers in their farm leases, and a tenant farmer were allowed to sell neither hay nor straw. Science has, however, changed all this, and a farmer in England can now usually grow whatever he pleases.

In England, however, with its high rents and its local land burdens and its fixed policy of free trade, which throws open our granaries to be filled by your good selves and our other cousins in other quarters of the globe, continuous wheat growing is no longer one of the directions in which our farmers can afford to use the freedom which has succeeded to the old restrictive farming. But for you continuous wheat growing must for a long time remain an economic possibility. The gradual reduction of your soils in nitrogenous fertility is slow, and, as necessity arises, can be amply met, as long as coal and nitrate of soda are abundant. We do not appear to be yet within sight of the end of the great nitrate deposits, and coal yields an increasing quantity of the other great concentrated nitrogenous fertilizer, ammonium sulphate; and there are, especially owing to your extensive animal and other industries, a great variety of other nitrogenous fertilizers, individually less concentrated, but of great aggregate quantity.

Some day, when the nitrate is all gone and the coal is used up, you may perhaps realize the prophecy of Sir William Crookes, and make "electric nitrate" (we already make "electric soda") from the nitrogen and oxygen of the air, using presumably tidal force, if your Niagara be too small, for generating the electricity needed to bring about the combination. But this is a dream of the very distant future.

MINERAL ELEMENTS OF FERTILITY.

We have been thus far mainly engaged, except for occasional digressions, in discussing questions relating to the supply and removal of nitrogen under various conditions. I would now direct your attention to the results of certain investigations into the quantity and condition of the phosphoric acid and potash contents of the various plats of this historic field.

Throughout the duration of the experiments, numerous ash analyses have been made of the crops, and the supply and removal of both phosphoric acid and potash with regard to most of the plats can be estimated with some reasonable approach to accuracy.

Until lately, however, no systematic series of determinations of phosphoric acid and potash have been made in the soils themselves. In 1894 the present lecturer had the honor to contribute a paper "On the determination of probably available 'mineral' plant food in soils,"[1] in which the use of a 1 per cent solution of citric acid was proposed as a means of approximate differentiation by means of analysis between the total and the probably available phosphoric acid and potash in soils.

[1] Journal of the Chemical Society, London, 65 (1894), pp. 115–167.

As the chemists of your country were good enough to take a great deal of interest in this paper, and to subject the citric-acid process to further investigation and to make it the point of departure for a number of alternative processes—some of which, no doubt, are better applicable to some kinds of soils and others to other kinds—I need not now say more about the inception of the process than to recall to you that it was the result of an attempt to imitate, in the solvent used, the acidity of the root-sap of flowering plants. This acidity was determined in 100 plants, representing some twenty different natural orders.

In order to test the proposed method it was applied to a large number of samples of soil from the continuous barley plats at Rothamsted, which had been preserved under very various manurial conditions for over forty years. The results of this investigation were referred to by Sir Henry Gilbert in his lectures to you, and he mentioned that I was then engaged in extending the investigation to the examination of the soils of the Broadbalk wheat plats. A number of the most typical plats were selected for this purpose, and the samples representing the first three depths, drawn in 1893, were examined, as well as corresponding samples, where these were available, drawn in 1865 and 1881. In all of these samples the total phosporic acid has been determined, and also the potash dissolved under certain conditions by strong hydrochloric acid. The quantities of phosphoric acid and potash dissolved by a 1 per cent solution of citric acid under the conditions originally laid down in my paper have also been determined. The results are fully discussed in a paper presented to the Royal Society of London.

As in considering the nitrogen results we have thus far confined our attention to the samples drawn in 1893, I will here follow the same procedure and will in like manner record the phosphoric acid and potash results for the 1893 samples, reserving until later a comparison between the newer and the older samples.

The accompanying table shows in a convenient form, for the series of plats submitted to mineral examination, the average yield of the plats as regards both grain and straw for forty-two years, 1852–1893, and for the six years 1889–1894; and also the quantities of phosphoric acid and potash applied to the soil during fifty years in the form of manure, and the quantities removed in the crops during the same period.

Table 53.—*Broadbalk wheat plats.*

Plat.	Manure per acre per annum.	Average yield per acre for 42 years, 1852–1893.		Average yield per acre for 6 years, 1889–1894.		Phosphoric acid.		Potash.	
		Wheat.	Straw.	Wheat.	Straw.	Estimated addition in manures during 50 years.	Estimated removal in crops during 50 years.*a*	Estimated addition in manures during 50 years.	Estimated removal in crops during 50 years.*a*
		Bu.	*Cwt.*	*Bu.*	*Cwt.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
3	Unmanured continuously	12¾	10⅝	12¾	9⅛	0	467	0	761
4	Unmanured continuously since 1852 (previously superphosphate and ammonium salts)	13½	10⅞	13⅛	9⅛	506	528	235	848
10a	Ammonium salts alone since 1844 (mineral manure in 1844)	19½	17¾	16½	13½	82	582	74	1,090
10b	Ammonium salts alone since 1844, except in 1846, 1848, and 1850 (mineral manure in 1844, 1848, and 1850)	21⅞	20	18	15¼	210	650	374	1,205
7	Ammonium salts and superphosphate, with 200 pounds potassium sulphate (300 pounds up to 1858), 100 pounds sodium sulphate (200 pounds up to 1858), and 100 pounds magnesium sulphate	32¾	32¾	34¼	33⅝	3,107	1,122	5,037	2,550
13	Ammonium salts and superphosphate, with 200 pounds potassium sulphate (300 pounds up to 1858). No sodium or magnesium salts	31¼	31⅛	32⅜	31¾	3,181	1,061	5,287	2,410
14	Ammonium salts and superphosphate, with 280 pounds magnesium sulphate (420 pounds up to 1858). No sodium or potassium salts since 1850	30¾	29⅜	29¼	27⅛	3,216	1,016	*b* 566	1,833
12	Ammonium salts and superphosphate, with 366½ pounds sodium sulphate (550 pounds up to 1858). No potassium or magnesium salts since 1851	30⅛	28½	29⅛	25⅝	3,189	1,005	*b* 588	1,743
11	Ammonium salts and superphosphate only. No potassium, sodium, or magnesium salts	24½	23	21⅜	20½	3,153	861	*b* 15	1,190
5	Superphosphate, with potassium, sodium, and magnesium sulphates, as on plat 7, but no nitrogen	14¾	12¼	14¾	10½	3,256	674	5,203	1,136
2b	14 tons farmyard manure (1843–44, and every year since)	34⅝	32¼	40⅞	38¾	3,920	1,301	11,760	2,478
2a	14 tons farmyard manure, commencing in 1884–85	-------	-------	30¼	28⅜	--------	--------	--------	--------

a Estimated from analysis of separate samples of grain and straw from each plat.
b Applied prior to 1852.

Phosphoric acid.

General Discussion and Statement of Analytical Results on Broadbalk Soils and Subsoils of 1893.

The total phosphoric acid was in each case determined in 10 grams of the dry soil by ignition and extraction with acid, duplicate determinations having in all cases been made, one with nitric acid as a solvent and the other with hydrochloric acid, the chlorin in the latter case being nearly eliminated from the solution after removal of the silica by repeated evaporation with nitric acid before adding the molybdic solution.

The citric-acid results were obtained by treating a large quantity of soil, usually 200 grams, with 1 per cent citric-acid solution in the proportions of 1 liter of solvent to 100 grams of soil, the soil being kept in the solution for seven days with frequent shaking. A quantity of solution representing 50 grams of the soil was taken for the determination of phosphoric acid.

The results for all the plats examined are given in the following table:

TABLE 54.—*Broadbalk wheat soils, samples collected in October, 1893*—PHOSPHORIC ACID *determinations.*

Plat.	Annual manuring.	Total phosphoric acid.						Phosphoric acid dissolved by a 1 per cent solution of citric acid.					
		First depth.		Second depth.		Third depth.		First depth.		Second depth.		Third depth.	
		Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
2a	Farmyard manure since 1884	0.165	4,142	0.095	2,538	0.084	2,345	0.0321	806	0.0052	139	0.0028	78
2b	Farmyard manure 50 years	.215	5,018	.111	2,965	.083	2,317	.0560	1,307	.0094	251	.0034	95
3	Unmanured	.114	2,956	.113	3,019	.097	2,708	.0078	202	.0041	110	.0021	59
4	Unmanured since 1852	.120	3,111	.106	2,832	.097	2,708	.0100	259	.0024	64	.0017	48
5	Full minerals	.219	5,678	.107	2,858	.112	3,126	.0642	1,665	.0052	139	.0036	101
7	Full minerals and ammonium salts	.195	5,056	.086	2,297	.074	2,066	.0547	1,418	.0038	102	.0030	84
10a	Ammonium salts (no minerals since 1844)	.123	3,189	.111	2,965	.105	2,931	.0074	192	.0031	83	.0018	50
10b	Ammonium salts (no minerals since 1850)	.126	3,267	.123	3,286	.111	3,099	.0074	192	.0043	115	.0021	59
11	Phosphates and ammonium salts	.197	5,107	.108	2,885	.091	2,540	.0405	1,050	.0028	75	.0017	48
12	Phosphates, sodium and ammonium salts	.201	5,211	.098	2,618	.082	2,289	.0413	1,071	.0035	94	.0020	56
13	Phosphates, potassium, and ammonium salts	.205	5,315	.105	2,805	.081	2,261	.0434	1,125	.0027	72	.0016	45
14	Phosphates, magnesium, and ammonium salts	.204	5,289	.111	2,965	.113	3,154	.0042	1,146	.0023	61	.0023	64

I would first direct attention to the figures representing the contents of the surface soil or first 9 inches, for it is in this depth that the variations in phosphoric acid are mainly found, the greater part of the unused phosphates applied to a soil containing so much clay as the Rothamsted loam being evidently mainly retained in the surface soil, though, as we shall see, some portion does, under some conditions, find its way into the subsoil.

The following table shows the percentages of total and citric-acid-soluble phosphoric acid in each separate plat, and the average yield of grain and straw for six recent years, viz, 1889–1894, the last named being the season following the soil sampling:

TABLE 55.—*Broadbalk wheat soils, samples collected in October, 1893.*

Plat.	Annual manuring for 50 years (with only minor variations during earlier years).	Phosphoric acid (P_2O_5) in fine dry soil (first 9 inches).		Average yield per acre (1889–1894).	
		Total.	Dissolved by 1 per cent citric-acid solution.	Wheat.	Straw.
		Per cent.	*Per cent.*	*Bushels.*	*Cwt.*
3	Unmanured continuously	0.114	0.0078	12¾	9⅛
4	Unmanured continuously since 1852	.120	.0100	13⅛	9⅛
10a	Ammonium salts only, since 1844	.123	.0074	16½	13½
10b	Ammonium salts only, since 1850	.126	.0074	18	15¼
7	Superphosphate and ammonium salts, with potassium, sodium, and magnesium sulphates	.195	.0547	34¾	33⅝
13	Superphosphate and ammonium salts, with potassium sulphate	.205	.0434	32⅜	31¾
14	Superphosphate and ammonium salts, with magnesium sulphate	.204	.0442	29¼	27⅛
12	Superphosphate and ammonium salts, with sodium sulphate	.201	.0413	29⅛	25⅝
11	Superphosphate and ammonium salts only	.197	.0405	21⅜	20½
5	Superphosphate and potassium, sodium, and magnesium sulphates (no nitrogen)	.219	.0642	24¾	10½
2b	14 tons farmyard manure	.215	.0560	40⅞	38¾
2a	14 tons farmyard manure (commencing in 1884–85)	.165	.0321	30¼	28⅜

These results may be condensed by averaging the four soils which have been wholly without phosphatic manure since 1850; and also the five soils continuously receiving superphosphate in conjunction with nitrogen.

TABLE 56.—*Broadbalk wheat soils, samples collected in October, 1893.*

Plats.	Annual manuring.	Average percentage of phosphoric acid in fine dry soil.		Average yield per acre (1889–1894).	
		Total.	Dissolved by 1 per cent citric-acid solution.	Wheat.	Straw.
		Per cent.	*Per cent.*	*Bushels.*	*Cwt.*
3, 4, 10a, and 10b	No phosphates	0.121	0.0082	15⅛	11¾
7, 13, 14, 12, 11	Superphosphate and ammonium salts, with and without alkaline salts.	.200	.0448	29½	27¾
5	Superphosphate and alkaline salts, without nitrogen.	.219	.0642	14¾	10½
2b	14 tons farmyard manure for 50 years.	.215	.0560	40⅞	38¾
2a	14 tons farmyard manure for 9 years only.	.165	.0321	30¼	28⅜

Of these four groups of plats, the first is suffering from phosphatic starvation, aggravated, in two of the four plats comprising it, by a free supply of ammonium salts. The average yield has dropped to a little over 15 bushels of grain per acre and less than 12 hundredweight of straw.

In the next group, of five plats, superphosphate has been freely and continuously supplied, as well as nitrogen in the form of ammonium salts, while on four out of the five plats of this group "alkaline" salts (potassium, sodium, and magnesium salts, together or separately) have been likewise applied annually. Here the average yield of grain is nearly double that of the former group, while the straw is more than two and one-fourth times as great.

Then we have the plat which has received continuously an abundance of phosphatic and other mineral manure, but no nitrogen. Its yield is now poorer on the average than even the first group, for it is suffering from nitrogen starvation—shown even more strongly in the low straw yield than in the low yield of grain. The yield of both grain and straw, though less than the average yield of the first group, is nevertheless better than that of the unmanured plats 3 and 4 included in it, which are suffering from both nitrogen and mineral starvation. But its yield of grain is only half that of the group of soils supplied annually with nitrogen as well as minerals, and its yield of straw is not much more than one-third. Since it has received practically the same supply of phosphatic manure per acre as this group, we should (apart from the information derived from analyses of the crops) expect to find an additional accumulation of phosphates in this plat over and above that found in group 2.

Then we have the farmyard manure plats, the one dunged liberally for fifty years leading the way with a yield well above that of any of the other groups, both as regards grain and straw, and the other subjected to this liberal treatment for nine years only, but still, in virtue of its comparatively newly acquired fertility, giving a better yield than the average of the chemically treated plats, though not so good a yield as the completely manured plat 13.

The differences in phosphoric-acid contents that one would be led to expect from the aforesaid considerations are qualitatively apparent in the figures for total phosphoric acid. Thus the second group shows greatly more phosphoric acid than the first group. Again, on the other hand, it shows less than plat 5. Intermediate is the long-dunged plat, while the plat more recently brought under dung treatment is intermediate between the first and second group.

But these differences in total phosphoric acid, significant as they clearly are, in soils from the same field, would convey, apart from a priori knowledge of their origin and of their circumstances, no such information as to suggest the profound differences really existing in the phosphatic condition of the soils.

To make this more clear, the figures are best reduced to a simple proportion, taking the average quantity of phosphoric acid in the first group as unity. We then have:

Number of plats.	Mode of manuring.	Ratio of total phosphoric acid to that of plats receiving no phosphates.
Four plats	No phosphates	1.00:1
Five plats	Phosphates and nitrogen, with and without alkaline salts.	1.65:1
One plat	Phosphates and alkaline salts only	1.81:1
Do.	Dung 50 years	1.78:1
Do.	Dung 9 years	1.36:1

The four plats in the first group contain, on the average, over 3,000 pounds of phosphoric acid per acre in the first 9 inches of soil, to say nothing of a further 6,000 pounds in the subjacent 18 inches. This is equivalent to nearly 3 tons of phosphate of lime per acre in the top soil, with 6 tons lying below, well within reach of the plant in its later stages of growth. In face of this enormous quantity of total phosphoric acid, the wheat crop, which under the most favorable circumstances does not need more (and usually needs less) than some 30 pounds of phosphoric acid per acre, is unable to do more than eke out a half-starved existence; the only explanation of which is that, of the total phosphates present, only a small proportion are in a form in which they can be utilized. Even in ordinary farming it is a familiar fact that, on soils containing a good deal more phosphoric acid than this, a few hundredweights of superphosphate per acre will often make the difference between a full crop of roots and one that is all but a failure. This being so, it is evident that such ratios as those just given for total phosphoric acid would have little significance if we wished to compare soils from different fields, or to judge of their relative mineral fertility, or forecast the probable advantage of applying phosphatic manure or the economy of withholding it.

If, on the other hand, we take the phosphoric acid dissolved by a 1 per cent solution of citric acid, we find differences of an altogether different character; for, while the ratios for total phosphoric acid between phosphatically manured and phosphatically unmanured plats were all comprised within a ratio of 2:1, we find the citric-acid-soluble ratios, as will be seen from the following table, to show approximately such numbers as 4:1, 5:1, and nearly 8:1.

Number of plats.	Mode of manuring.	Ratio of phosphoric acid soluble in 1 per cent citric-acid solution to that of plats receiving no phosphates.
Four plats	No phospates	1.00:1
Five plats	Phosphates and nitrogen, with and without alkaline salts	5.46:1
One plat	Phosphates and alkaline salts only	7.83:1
Do	Dung 50 years	6.83:1
Do	Dung 9 years	3.91:1

Clearly the percentage of citric-acid-soluble phosphoric acid gives us overwhelmingly clearer qualitative information as to the condition of the soils than any that could be arrived at from a study of the mere total percentages, apart, as aforesaid, from a priori topographical and historical knowledge.

Probable Limit Denoting Phosphoric-Acid Deficiency in Soils.

It will have been noticed that in only one case, on the phosphatically unmanured plats, does the phosphoric acid soluble in citric acid reach 0.01 per cent of the surface soil, the average number for these four plats being 0.0082 per cent, corresponding to a little over 200 pounds per acre. This figure corresponds almost exactly with the mean figure obtained for the soils of the eight phosphatically starved barley plats from Hoos field, from the results of which I ventured to draw the tentative conclusion that when a soil is found by analysis to contain as little as about 0.01 per cent of phosphoric acid soluble in a 1 per cent solution of citric acid, used as described, it would be justifiable (as far as cereals are concerned) to assume that it stands in immediate need of phosphatic manure. That conclusion, therefore, appears to be well maintained by the new results obtained from the wheat soils. How far we may go in the other direction, in venturing to fix a limit which shall be indicative of the nonnecessity of phosphatic manure, is a more difficult question to decide. The soils of the various superphosphate-manured wheat plats in Broadbalk field, like those of the corresponding barley plats in Hoos field, have been abundantly or overabundantly supplied, and would probably grow undiminished crops for some years to come, if the annual supply of phosphatic manure ceased, nitrogen (and other minerals) being supplied as usual. Those included in our series average from 0.04 to 0.05 per cent of citric-acid-soluble phosphoric acid—almost identically the averages found for the various corresponding barley soils. That this is indicative of superabundance of phosphates is evident from the fact that plat 8, receiving the same dressing of mineral manures, but receiving half as much again of nitrogen (600 pounds ammonium salts per acre), has consistently yielded considerably larger crops. We seem thus in a position to say that the limit of phosphatic sufficiency for cereal crops is somewhere below 0.04 per cent of citric-acid-soluble phosphoric acid, while as little as about 0.01 per cent indicates phosphatic starvation.

The plat (2b) continuously dunged for fifty years gives 0.056 per cent, and is probably saturated with mineral fertility. Its yield is inferior to that of the most liberally manured chemical plat of the field (not represented in our table), owing, it may be supposed, to an insufficient annual supply of nitrogen in a rapidly available form.

Plat 2a has been dunged for over nine years. Previously, for nearly thirty-five years, it was unmanured, except for partial dressings of alkaline sulphates. Its yield is about equal to the average of the chemically manured plats included in our table, though inferior to the best of them. It contains 0.03 per cent of citric-acid-soluble phosphoric acid. From various considerations it appears probable that the lower yield of plat 2a, as compared with the much longer dunged plat 2b, is rather due to a deficiency in the yearly supply of available nitrogen than to deficiency in the present supply of mineral food. If this were the case our limit indicative of phosphatic sufficiency would be reduced from 0.04 to 0.03 per cent of citric-acid-soluble phosphoric acid.

The probable limit, then, denoting phosphatic deficiency for cereals seems to be, as deduced from this investigation, between 0.01 per cent and 0.03 per cent of citric-acid-soluble phosphoric acid in the surface soil; that is to say, a percentage as low as 0.01 seems to denote an imperative necessity for phosphatic manuring, while as much as 0.03 per cent would seem to indicate that there is no such immediate necessity. For root crops, more especially turnips, the limits would probably be higher.

Brief Examination of the Results Obtained for Individual Plats.

In view of the fuller discussion of the detailed results in the paper presented to the Royal Society, it will suffice here to confine our attention to some of the more striking indications obtained by comparison of the analytical results with the estimated removal or accumulation of phosphoric acid during the fifty years.

Plat 3, it will be remembered, is continuously unmanured. Plat 4 received some mineral dressings in its earlier years, but in 1893 it had been for forty-two years unmanured. Assuming the phosphoric acid originally present in the two soils to have been alike, plat 4 should now contain 445 pounds more phosphoric acid per acre than plat 3. We actually find by analysis 155 pounds more of total phosphoric acid in the surface soil, 58 pounds of this being soluble in dilute citric-acid solution.

Plats 10a and 10b have both continuously received ammonium salts without phosphates, except that plat 10b had some mineral dressings in its earlier years. Plat 10b should contain 60 pounds per acre more phosphoric acid than plat 10a. We actually find by analysis in the surface soil 78 pounds more. The citric-acid-soluble phosphoric acid is the same in the surface soil in both plats, but in the second and third depths plat 10b shows an excess of 41 pounds per acre as compared with plat 10a.

We shall see, hereafter, from the analyses of the earlier samples, that on plats 3, 10a, and 10b, especially the two latter, the surface soils have probably reached the stage at which the quantity of mineral food annually rendered available by natural processes, including the decay of roots and stubble, balances the annual output in the crops.

For the various chemically manured plats receiving phosphoric acid the results are tabulated below:

TABLE 57.—*Broadbalk wheat soils, samples collected in October, 1893—Plats 7, 13, 14, 12, 11, and 5, receiving chemical fertilizers, including phosphates.*

Plat.	Annual manuring.	Estimated excess of phosphoric acid per acre over plat 3, calculated from known additions and removals.	Excess of total phosphoric acid per acre, found by analysis in first 9 inches of soil.	Excess (+) or deficiency (—) of phosphoric acid (per acre) soluble in 1 per cent citric-acid solution, as compared with plat 3.			
				First 9 inches.	Second 9 inches.	Third 9 inches.	1 to 27 inches.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
7	Full minerals and ammonium salts	2,452	2,110	+1,216	− 8	+25	+1,233
13	Phosphates, potassium and ammonium salts	2,587	2,359	+ 923	−37	−14	+ 872
14	Phosphates, magnesium and ammonium salts	2,667	2,333	+ 944	−48	+ 6	+ 902
12	Phosphates, sodium and ammonium salts	2,651	2,255	+ 869	16	3	+ 850
11	Phosphates and ammonium salts only	2,759	2,151	+ 848	−35	−11	+ 802
5	Full minerals without ammonium salts	3,049	2,722	+1,462	+29	+42	+1,533

It will be seen that the greater part of the calculated excess of phosphoric acid is actually found in the surface soils, namely, from 79 to 91 per cent. It would appear that in the course of years some of the phosphoric acid has descended lower, but it is to be remembered that the accumulations are calculated on the supposition that the soils were all originally alike in phosphoric-acid contents, and, further, that most of the deficit between the calculated accumulations and those actually found in the surface soil are comprised within a difference equal to only 0.01 per cent of phosphoric acid calculated on the surface soil. Nevertheless, as the difference is always in the direction of deficiency, it seems probable that on the whole it is attributable to descent. Unfortunately, the natural variations in the total phosphoric acid of the subsoils are too great to enable us to verify the subsoil accumulation of total phosphoric acid.

Broadly speaking, the results show beyond doubt that the unused phosphates, though applied in a soluble form, are mainly retained near the surface.

Of the total phosphates added to the soil in the fertilizers, probably nine-tenths would be in a condition originally soluble in weak citric-acid solution; but the unused portion, even of the originally soluble phosphates, would enter into more or less firm combination with the bases of the soil, as shown by the retention of its main bulk in the surface soil. It is of interest to see how much of the accumulated quantity is still to be found in the condition of ready solubility in weak citric-acid solution. Of the quantity found in this condition, a part will no doubt be due to root and stubble residue, but in these plats the main portion found in the surface soil may be taken as due to unappropriated manure.

The proportion found is at once seen to be large, but variable, and we shall presently see that this variability bears an interesting relation to the fertilizers which have been applied together with the superphosphate.

In the second and third depths, except in two cases, none of the phosphoric acid which may have descended appears now to exist in the citric-acid-soluble condition. Some of the phosphoric acid which may have descended may well have reverted into a condition insoluble in citric acid; but the deficiency of citric-acid-soluble phosphoric acid in the lower depths may very possibly be related in some cases to the more vigorous plant growth on these plats, as compared with the unmanured plat. Being manured with both nitrogen and phosphates, the roots of the wheat may have developed more vigorously in the second and third depths of the soil, producing a greater strain on the phosphoric-acid resources of the subsoil, notwithstanding the abundance of phosphatic food above.

It will be seen that two of these plats differ notably from the others in subsoil contents of citric-acid-soluble phosphoric acid, namely, plats 5 and 7. These two plats alone, in addition to phosphoric acid, have had persistently applied to them potassium, sodium, and magnesium salts, 400 pounds per acre per annum in the aggregate. To three of the other four plats one or other of these salts has been applied, but only to these two plats have all three salts been given.

One of the two, plat 7, has received ammonium salts also, in the same quantities as plats 11 to 14. The other, plat 5, has received the same full phosphatic and saline dressing, but without ammonium salts.

The last-named plat, getting no nitrogen, has yielded a very small average crop, and has naturally accumulated a far larger quantity of phosphoric acid, nearly 500 pounds more per acre being found by analysis in the first 9 inches than in the average of the other plats. As might be expected, there is also a much larger accumulation of citric-acid-soluble phosphoric acid, and the proportion of citric-acid-soluble to total accumulation is greater than in the average of the other plats. Further, in both the second and third depths we find a tangible excess of citric-acid-soluble phosphoric acid beyond that in the unmanured plat, showing that the available phosphoric acid in the subsoil has been in excess of the demands of the crops. This appears to be due not merely to the absence of nitrogen and consequent small growth and small assimilation of phosphates, for plat 7, which receives ammonium salts with the same full mineral dressing, has persistently yielded a much larger crop both of grain and straw than any of its companions. Its output of phosphates has consequently been greater, and its accumulation less; but instead of being poorer in available or citric-acid-soluble phosphoric acid than its companions, it is now richer to the extent of some hundreds of pounds per acre, though, as might be expected, it is not so rich as plat 5.

It is also, as regards citric-acid-soluble phosphoric acid, appreciably richer than the other plats in the second and third depths, though not to the same extent as plat 5.

It would seem that the full supply of soluble salts has either exerted a solvent action on the natural store of otherwise unavailable phosphoric acid in the soil, or, which is more probable, that the manurial phosphates have entered into some sort of combination with the saline bases and have been retained in a less insoluble condition than where these have been absent or less in quantity. This kind of solvent action is greatest where a full supply of saline matters has accompanied that of phosphatic manure, but it is also shown to exist in the case of the smaller separate applications of potassium, magnesium, and sodium salts.

On plat 11, where phosphates and ammonium salts only have been used, although there has been less demand on the phosphoric acid, the quantity of citric-acid-soluble phosphoric acid is least. This is shown in the following table:

TABLE 58.—*Broadbalk wheat soils, samples collected in October, 1893—Plats 5, 7, 13, 14, 12, and 11.*

Plat.	Annual manuring.	Ratio of excess of citric-acid-soluble phosphoric acid found per acre (as compared with unmanured plat) to calculated excess of total phosphoric acid, the calculated excess in each case being taken as 100. First 9 inches.	27 inches.
		Per cent.	*Per cent.*
5	Phosphates, potassium, sodium, and magnesium salts	48	50
7	Ammonium salts, phosphates, and potassium, sodium, and magnesium salts	50	50
13	Ammonium salts, phosphates, and potassium salts	26	34
14	Ammonium salts, phosphates, and magnesium salts	35	34
12	Ammonium salts, phosphates, and sodium salts	33	32
11	Ammonium salts and phosphates only	31	29

In the case of the dunged plats there is a far larger excess of phosphoric acid unaccounted for. It may be remembered that plat 2b has yearly received since 1843 a dressing of 14 tons per acre of farmyard manure. Plat 2a was unmanured from 1849 to 1883, except that a portion of it received alkaline salts. Since 1883 it has received the same treatment as plat 2b, viz, 14 tons of dung per annum. The former plat has yielded on the average, for fifty years, over 34$\frac{5}{8}$ bushels of wheat and 32$\frac{1}{4}$ hundredweight of straw per acre, a better yield than that of any of the other plats already considered, though inferior to that of plat 8, already alluded to, which in addition to a full dressing of mineral manures has received 600 pounds of ammonium salts per annum.

During the last six years of the period of fifty years which we are considering plat 2b yielded 40⅞ bushels of grain per annum and 38¾ hundredweight of straw, while plat 7 (400 pounds of ammonium salts, with full minerals) averaged only 34¾ bushels of wheat and 33⅝ hundredweight of straw. During the same six years plat 2a averaged 30¼ bushels of wheat and 28⅜ hundredweight of straw. Clearly, therefore, plat 2b has reached, as would be expected, a state of high fertility, while plat 2a, though at the time of the last soil sampling it had for nine years received the same treatment as 2b, was nevertheless far behind it in fertility, the previous forty years of dung still telling very markedly on the latter plat. It is much more difficult to estimate the yearly addition of phosphoric acid to the dunged plats than to estimate it in the case of the chemically manured plats, for the phosphatic manures are of fairly definite and uniform composition, while dung is necessarily variable and is very difficult to sample so as to fairly represent an annual application of 14 tons per acre. Any estimate is therefore, at the best, to be regarded as only an approximation. Sir Henry Gilbert estimates that the dung applied contains 0.25 per cent of phosphoric acid, and since this small percentage represents in fifty years 3,920 pounds per acre, it is clear that there is room for considerable error. If the estimate of 0.25 were 0.05 too high or too low as compared with the real average percentage in a material of so indefinite and so fluctuating a composition as farmyard manure, the error of estimate on the fifty years would amount to nearly 800 pounds.

In the following table the estimate of 0.25 per cent is, however, taken.

Plat 3 (continuously unmanured) is again taken as a standard, the sum of the estimated loss of phosporic acid per acre on plat 3 and of the estimated gain on plat 2b representing the estimated excess per acre in the latter plat.

TABLE 59.—*Broadbalk wheat soils, samples collected in October, 1893—Plat 2b manured with 14 tons farmyard manure per acre per annum for fifty years.*

	Pounds.
Estimated excess of total phosphoric acid per acre over plat 3, at the end of fifty years	3,086
Excess of total phosphoric acid per acre over that in plat 3, found by analysis in first 9 inches of soil	2,062
Excess of phosphoric acid per acre (as compared with plat 3) soluble in 1 per cent citric-acid solution, found in—	
First 9 inches	1,105
Second 9 inches	141
Third 9 inches	36
Total (27 inches)	1,282

It is evident that, if the estimated quantity of phosphoric acid applied in the farmyard manure throughout the period of fifty years is correct, a very much larger quantity of phosphoric acid in the form of dung must have descended into the subsoil than has been the case on the plats manured with superphosphate. Even if we allow some considerable margin in the estimate, it still appears that there must have been a considerable descent. Unfortunately the irregularity in the mineral composition of the subsoils, to which reference has already been made, makes it impracticable to trace the descent quantitatively as far as total phosphoric acid is concerned. The descent, nevertheless, is qualitatively seen in the increase of citric-acid-soluble phosphoric acid in both the second and third depths. Of the excess of total phosphoric acid (as compared with plat 3) actually found arrested in the first 9 inches, considerably more than half exists in the citric-acid-soluble state, forming a large reserve of phosphoric fertility. This reserve, as we have seen, is far from being confined to the surface soil, though much of the phosphoric acid which must be supposed to have descended into the subsoil has evidently assumed a less available form.

This greater descent of phosphoric acid into the subsoil in the case of the dunged plats, as compared with the artificially fertilized plats, is a point of much interest. The reason for it may be a merely chemical one. We have seen that in the case of plats 5 and 7, where alkaline salts have been liberally applied, these have markedly influenced the condition of the phosphoric acid as compared with that on the plats on which no alkaline salts were used; and the saline matters of the dung may have had some similar effect. It also seems just possible that earthworms may play a part in the distribution of the constituents of the dung, by devouring it and conveying it downward.

In the case of plat 2a, which had been dunged for only nine years at the time at which the last soil samples were taken, the total excess of phosphoric acid over plat 3 actually found by analysis is 1,186 pounds per acre, whereas the estimated excess should only be 592 pounds; but the excess found in a citric-acid-soluble condition is 604 pounds in the first 9 inches, 29 pounds in the second 9 inches, and 19 pounds in the third 9 inches, a total excess of 652 pounds per acre as compared with plat 3.

The calculated excess of course involves not only the supposition that the dung was on the average of uniform composition, but also the supposition that the soils were uniform to begin with, and there is no evidence to show that such was actually the case.

Viewing the figures broadly it is at any rate evident that much less of the dung phosphates applied to this plat during the nine years have reverted to the insoluble condition than in the case of the older dung accumulations on plat 2b. The influence of the dung on the available phosphoric acid of the subsoil is also much less marked than in the case of the plat dunged for fifty years; nevertheless it is apparent.

Phosphoric Acid in Drainage Waters.

Upward of thirty years ago the late Dr. Augustus Voelcker made analyses of several series of samples of the pipe-drainage waters collected from the Broadbalk wheat plats. The results were published in a paper "On the composition of waters of land drainage," referred to on p. 86, and was subsequently summarized in a Rothamsted paper, "On the amount and composition of the rain and drainage waters collected at Rothamsted." (See p. 49.)

These are the only fairly complete mineral analyses that have been made of the drainage waters, although for many years constant determinations have been made of nitric nitrogen and chlorin. Averaging the various samples from each plat analyzed by Dr. Voelcker, we have the following results:

Table 60.—*Analyses of Broadbalk field drainage waters made by the late Dr. Augustus Voelcker, F. R. S., 1866–1869.*

[Parts per million.]

	Annual manuring.	Average quantity of phosphoric acid in drainage water.
Plats 3 and 4	Unmanured	0.63
Plat 10	Ammonium salts only	1.44
Plat 5	Full mineral dressing without nitrogen	.91
Plat 7	Ammonium salts and full mineral dressing	.91
Plat 11	Ammonium salts and superphosphate	1.66
Plat 12	Ammonium salts, superphosphate, and sodium sulphate	1.26
Plat 13	Ammonium salts, superphosphate, and potassium sulphate	1.09
Plat 14	Ammonium salts, superphosphate, and magnesium sulphate	1.01

If we assume a downward percolation of 10 inches of drainage water per annum, one part per million of water corresponds, in round numbers, to 2¼ pounds per acre per annum. According to this estimate, the average variations in phosphoric acid washed away in the drainage waters, as shown in Dr. Voelcker's analyses, are from 1½ to 3¾ pounds per acre per annum.

To some extent the differences found bear a relation to the manuring and cropping conditions of the plats, but not altogether, and it is to be remembered that the actual quantities analytically dealt with amounted only to small fractions of a grain of phosphoric acid per gallon of water; and furthermore, that the methods for the quantitative estimation of minute quantities of phosphoric acid thirty years ago were not quite so delicate as they are at the present time. Too much stress, therefore, must not be laid upon the quantitative differences.

Substantially, however, the results seem to show that no very appreciable quantity of manurial phosphoric acid passes away annually in the drainage water from the chemically manured plats, and that there is not a very great difference between the quantity of phosphoric acid in the drainage water from the unmanured plats on the one hand and the very highly phosphated plats on the other, though the descent by drainage may of course have become greater in later years, as phosphates have accumulated.

Unfortunately, Dr. Voelcker made no determinations of the phosphoric acid existing in the drainage water from the dunged plat 2b. As has been mentioned elsewhere, the absorptive character of the soil of this plat is such that it is very retentive of moisture, and the drain-pipes very seldom run except in very wet weather, and Dr. Voelcker was unable to obtain samples of the drainage water from this plat when the other samples were collected.

General Conclusions as to Phosphoric Acid.

The general conclusions derived from the phosphoric-acid results, as summed up in the paper recently laid before the Royal Society,[1] are to the effect that by far the greater proportion of the unconsumed phosphoric acid in the manure is accumulated in the surface soil, although for the most part originally soluble in water. In the case of dung there is a considerable descent into the second and third depths of 9 inches, and there is also evidence of considerable descent into the second and even into the third depths in those cases in which superphosphate has been accompanied by constant dressings of potassium, sodium, and magnesium salts. The greater part of the calculated accumulation, however, is found by analysis in the surface soil, and a large proportion of it is found in a condition in which it dissolves in a weak solution of citric acid.

While the differences between the total percentages of phosphoric acid in the surface soil correspond fairly with the history of the plats, they would not suffice, in the absence of a knowledge of such history, to give any adequate indication of the profound differences in phosphatic condition which we know to exist. But the relative proportions of citric-acid-soluble phosphoric acid appear to afford a striking index to the relative phosphatic fertility of the soils. In the case of the subsoil samples the irregularities and variations in the natural or original phosphoric acid of the subsoils themselves are such that the total percentages tell us, as a rule, nothing, while the citric-acid results frequently show striking and consistent differences, and are also of considerable interest in connection with the problems of root range and subsoil feeding.

The influence of akaline salts on the retention of phosphoric acid in a less fixed and presumably more available condition is interesting, corresponding as it does with the increase of saline applications.

The superabundance of phosphoric acid estimated to have been supplied in dung over fifty years is less satisfactorily accounted for than is the case with the phosphoric acid in the chemically manured

---

[1] Philosophical Transactions of the Royal Society [England], 1901, series B, vol. 194, pp. 235-290.

plats. This may be partly accounted for by the supposition that the phosphoric acid contained in the dung, at any rate over a portion of the time, may have been overestimated, but there appears reason for supposing that there has been a greater descent into the subsoil in the case of the plat dunged for fifty years than in the case of the chemically manured plats. On the plat dunged for nine years only we find the estimated accumulation fairly represented in the upper depths—for the most part in the first 9 inches.

As in the case of nitrogen, the soil possesses naturally a very large reserve of phosphoric acid, but again, as in the case of nitrogen, the quantity annually rendered available for the use of plants by natural soil processes is insufficient to suffice for the needs of anything like an average crop.

Potash.

General Discussion and Statement of Analytical Results on Broadbalk Soils and Subsoils of 1893.

The total potash has not been determined in the various samples. The Broadbalk soil, like most soils containing much clay, contains a great quantity of potash in the form of silicates decomposable only by fusion or by treatment with hydrofluoric acid. The quantity of potash, including this, is between 1 and 2 per cent in the surface soil and probably more in the subsoil. This means that in the first 9 inches of soil there are probably 15 tons of potash per acre in a dormant form, while the quantity in each succeeding depth is probably greater. Such potash forms a reserve stock for the distant future, and is no doubt very gradually rendered available for plant use by the natural processes going on within the soil. But, even with this great reserve of total potash, the soil is unable to furnish a sufficient annual supply to the wheat crop under a system of continuous cropping.

It is usual in soil analysis to neglect to take into account potash existing in so insoluble a form as to be separable only by means of fusion or treatment with hydrofluoric acid, for such potash is obviously far removed from the range of present utility, and only to take into account such potash as is soluble in hydrochloric acid. It is by this time well recognized, however, that even this solvent extracts, at all events in many cases, far more potash than can be in any sense regarded as of present utility. Unfortunately, this is not the only unsatisfactory aspect of the determination of potash by hydrochloric-acid extraction. The quantity of potash extracted varies greatly, not only with the strength and quantity of acid used, but also with the duration of the process and with the temperature.

The potash dissolved by hydrochloric acid was, however, determined in a large number of samples, the quantity of soil taken for the determination being 10 grams, and the extraction being made by treatment and evaporation to dryness with 50 cubic centimeters of strong hydrochloric acid, the residue being redigested on the water bath for one hour with 25 cubic centimeters of strong hydrochloric acid.

The citric-acid-soluble potash was determined in the solution obtained on treatment of 200 grams of the soil, as already described under the heading of phosphoric acid, the potash being determined in a quantity of solution representing 50 grams of soil.

The results for the 1893 samples were as follows:

TABLE 61.—*Broadbalk wheat soils, samples collected in October, 1893*—POTASH *determinations.*

POTASH DISSOLVED BY STRONG HYDROCHLORIC ACID.

Plat.	Annual manuring.	First depth.		Second depth.		Third depth.	
		Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
2a	Farmyard manure since 1884	0.277	6,953	0.398	10,632	0.415	13,930
2b	Farmyard manure 50 years	.285	6,652	.318	8,495	.499	11,585
3	Unmanured	.220	5,704	.335	8,949	.495	13,818
4	Unmanured since 1852	.219	5,678	.414	11,059	.507	14,153
5	Full minerals	.279	7,233	.410	10,952	.472	13,176
7	Full minerals and ammonium salts	.262	6,793	.361	9,643	.459	12,813
10a	Ammonium salts (no minerals since 1844)	.240	6,222	.394	10,525	.533	14,879
10b	Ammonium salts (no minerals since 1850)	.234	6,067	.359	9,590	.507	14,153
11	Phosphates and ammonium salts	.197	5,107	.357	9,537	.459	12,813
12	Phosphates, sodium, and ammonium salts	.223	5,782	.371	9,911	.488	13,623
13	Phosphates, potassium, and ammonium salts	.273	7,078	.379	10,124	.433	12,087
14	Phosphates, magnesium, and ammonium salts	.240	6,222	.404	10,792	.408	11,389

POTASH DISSOLVED BY A 1 PER CENT SOLUTION OF CITRIC ACID.

Plat.	Annual manuring.	First depth.		Second depth.		Third depth.	
		Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
2a	Farmyard manure since 1884	0.0330	828	0.0168	449	0.0096	268
2b	Farmyard manure 50 years	.0384	896	.0276	737	.0128	357
3	Unmanured	.0032	83	.0060	160	.0072	201
4	Unmanured since 1852	.0052	135	.0060	160	.0044	123
5	Full minerals	.0308	799	.0224	598	.0092	257
7	Full minerals and ammonium salts	.0232	602	.0140	374	.0064	179
10a	Ammonium salts (no minerals since 1844)	.0032	83	.0032	86	.0048	134
10b	Ammonium salts (no minerals since 1850)	.0040	104	.0052	139	.0036	101
11	Phosphates and ammonium salts	.0032	83	.0028	75	.0036	101
12	Phosphates, sodium, and ammonium salts	.0040	104	.0040	107	.0036	101
13	Phosphates, potassium, and ammonium salts	.0188	487	.0136	363	.0084	235
14	Phosphates, magnesium, and ammonium salts	.0024	62	.0048	128	.0052	145

As far as regards the hydrochloric-acid-soluble potash, attention need only be directed to the surface soils, though in the case of the citric-acid-soluble potash it will be of interest to consider the results for all the three depths examined. The hydrochloric-acid figures, however, for the second and third depths appear to have so little practical meaning that they may be left out of consideration, for the quantity of potash dissolved by the mineral acid in these lower depths is vastly in excess of the potash which, from any point of view, can be regarded as of nearly prospective utility, and its variations are obviously so independent of the manurial treatment and cropping history of the soils as to deprive them of apparent practical significance.

The more important results may be conveniently studied in the following table:

TABLE 62.—*Broadbalk wheat soils, samples collected in October, 1893.*

Plat.	Annual manuring for 50 years (with only minor variations during the earlier years).	Potash in fine dry soil.				Average yield per acre, 1889–1894.	
		Dissolved by hydrochloric acid.	Dissolved by 1 per cent citric-acid solution.				
		First 9 inches.	First 9 inches.	Second 9 inches.	Third 9 inches.	Wheat.	Straw.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Bushels.*	*Cwt.*
3	Unmanured continuously	0.220	0.0032	0.0060	0.0072	12¾	9⅛
4	Unmanured continuously since 1852	.219	.0052	.0060	.0044	13⅛	9⅛
10a	Ammonium salts only since 1844	.240	.0032	.0032	.0048	16½	13½
10b	Ammonium salts only since 1850	.234	.0040	.0052	.0036	18	15¼
11	Ammonium salts and superphosphate	.197	.0032	.0028	.0036	21⅜	20½
12	Ammonium salts, superphosphate, and sodium sulphate (some potassium salts prior to 1852)	.223	.0040	.0040	.0036	29½	25⅝
14	Ammonium salts, superphosphate, and magnesium sulphate (some potassium salts prior to 1852)	.240	.0024	.0048	.0052	29¼	27⅛
13	Ammonium salts, superphosphate, and potassium salts	.273	.0188	.0136	.0084	32⅜	31¾
7	Ammonium salts, superphosphate, and potassium, sodium, and magnesium sulphates	.262	.0232	.0140	.0064	34¾	33⅝
5	Superphosphate and potassium, sodium, and magnesium sulphates (no nitrogen)	.279	.0308	.0224	.0092	14¾	10½
2b	14 tons farmyard manure	.285	.0384	.0276	.0128	40⅞	38¾
2a	14 tons farmyard manure (commencing in 1884–85)	.277	.0330	.0168	.0096	30¼	28⅝

It will be seen that we have a series of plats of which some are wholly unmanured, some manured with ammonium salts only, and several with both ammonium salts and phosphates. Of these last, one plat is without alkalies, one receives sodium salts, another magnesium salts, one potassium salts, and another all of these materials. We see that plat 11 without alkalies, though abundantly supplied with nitrogen and phosphates, has evidently largely exhausted the readily available potash of the soil by comparing its recent yield of wheat and straw (more especially the latter) with that of the potash plat 13. We also see that, either in virtue of certain applications of potassium salts forty years or more ago or in virtue of the solvent action on soil potash of the sodium and magnesium salts applied every year, plats 12 and 14 are very much more fertile than plat 11, though distinctly less fertile than plat 13, which gets an abundance of potassium salts, and still less so than plat 7, which gets all three salts.

The results of the determinations of hydrochloric-acid-soluble potash in the first depths and of the citric-acid-soluble potash in all three depths of the various plats will be seen to possess great interest and are worthy of consideration in detail.

For the moment, however, we may advantageously condense our table as we did in the case of phosphoric acid and consider the average results given, respectively, by the plats manured and unmanured with potash salts and with dung. These are as follows:

TABLE 63.—*Broadbalk wheat soils, samples collected in October, 1893.*

Plat.	Annual manuring for 50 years (with some variations during the earlier years).	Average potash in fine dry soil.				Average yield per acre, 1889-1894.	
		Dissolved by hydrochloric acid	Dissolved by 1 per cent citric acid solution.				
		First 9 inches.	First 9 inches.	Second 9 inches.	Third 9 inches.	Wheat.	Straw.
		Per cent.	*Per cent*	*Per cent*	*Per cent*	*Bushels.*	*Cwt.*
3 4, 10a, 10b, 11, 12, and 14.	No potash salts, except odd dressings in early years on 10 b, 12 and 14.	0.225	0.0036	0.0046	0.0046	20	17⅛
13, 7, and 5	All manured annually with dressings, including potash salts.	.271	.0243	.0167	.0080	27¼	25½
2b	14 tons farmyard manure yearly.	.285	.0384	.0276	.0128	40⅞	38¾
2a	14 tons farmyard manure, commencing only in 1884-85.	.277	.0330	.0168	.0096	30¼	28⅝

The continuous application of potash, whether in the form of potash salts or of dung, had made itself evident in the hydrochloric-acid-soluble potash. But there is no such difference as, apart from knowledge that the samples are from the same field, would suffice to lead to the conclusion that the soils of the first group were, from a practical point of view, deficient in potash. Taking the averages for the first group as unity, we find the following ratios:

Number of plats.	Mode of manuring.	Ratio of hydrochloric-acid-soluble potash to that in 7 non-potash plats.
7 plats	Without potash for forty years	1.00 : 1
3 plats	Potash dressed	1.20 : 1
1 plat	Dung fifty years	1.27 : 1
1 plat	Dung nine years	1.23 : 1

A comparison of the citric-acid-soluble potash, however, appears to be much more instructive as to the potash condition of the soils. The ratios are as follows:

Number of plats.	Mode of manuring.	Ratio of citric-acid-soluble potash to that in the 7 nonpotash plats.		
		First 9 inches.	Second 9 inches.	Third 9 inches.
7 plats	Without potash for forty years	1.00 : 1	1.00 : 1	1.00 : 1
3 plats	Potash dressed	6.75 : 1	3.63 : 1	1.74 : 1
1 plat	Dung fifty years	10.67 : 1	6.00 : 1	2.78 : 1
1 plat	Dung nine years	9.17 : 1	3.65 : 1	2.09 : 1

These figures are so striking that but little comment on them appears to be necessary. The chemically manured potash plats show in the first 9 inches nearly seven times as much citric-acid-soluble potash as those left without potash dressings, and in the second 9 inches about three and a half times as much, while even in the third depth there is nearly twice as much, showing that even in these clayey loams potash salts do, to an appreciable extent, find their way downward into the lower subsoil. The greater portion of the accumulation, however, is (in accordance with the generally accepted views of the chemistry of fairly heavy soils) found to be in the upper soil, where the potash appears to enter into more loose combination with the constituents of the clay.

In the continuously dunged soil, where the estimated excess of potash applied has been much greater, we find in the top soil more than ten times as much citric-acid-soluble potash as in the nonpotash plats, in the second 9 inches six times as much, and in the third 9 inches nearly three times as much; while even in the plat dunged for nine years only we find nine times as much in the top soil, three and a half times as much in the second 9 inches, and twice as much in the third. It would seem as though the potash of the dung, possibly in some organic state of combination, descends more easily into the subsoil than do the inorganic potash salts. This point, however, will claim our attention later.

In the paper on the Hoos field barley soils a tentative conclusion was drawn that the percentage of citric-acid-soluble potash in the surface soil indicative of potash hunger would for cereals probably lie below 0.005. On considering the results of the wheat soil analyses and other results obtained in the interim by workers who have applied the method to other soils known from experience to be responsive to the influence of potassium salts, the lecturer would now be inclined to modify this conclusion by suggesting that when a soil contains as much as 0.01 per cent of citric-acid-soluble potash as determined by this process it may be regarded as not demanding any special application of potassium salts.

Brief Examination of the Results Obtained in the Case of Individual Plats.

Plat 3 has been unmanured for fifty years. Plat 4 has been unmanured for forty years, but previously was annually dressed with superphosphate and ammonium salts, and has in consequence ever since given a slightly better yield than plat 3. (See Table 53.) It was never regularly manured with potash, but in its first year, fifty years prior to 1893, it had a dressing of farmyard manure ashes, estimated to have supplied 235 pounds per acre of potash. In fifty years it has yielded in its crops 87 pounds of potash per acre more than plat 3, but owing to the initial supply referred to its actual loss in cropping has been 140 pounds less per acre than that of plat 3. This difference is not indicated in the hydrochloric-acid figures, but it is qualitatively indicated in the surface-soil contents of citric-acid-soluble potash, there being found by analysis in 1893 in the surface soil an excess of 52 pounds per acre in this form as compared with plat 3.

Plats 10a and 10b have, it will be remembered, been continuously dressed with ammonium salts without minerals, except that, while both plats had a dressing of minerals in 1844, plat 10b was also dressed with minerals in 1848 and 1850. The effect of these two extra dressings of minerals on the yield of plat 10b is apparent in the crops down to the present day. The extra minerals applied to plat 10b included 300 pounds of potash per acre, and this plat has yielded in its crops, up to 1893, 115 pounds more potash per acre than plat 10a. Deducting the excess in yield from the excess in supply, plat 10b has lost less potash in its crops by 185 pounds per acre than plat 10a. Here, again, the hydrochloric-acid results indicate no difference, but in the citric-acid results we find that plat 10b shows 21 pounds more citric-acid-soluble potash in the first depth, and 53 pounds more in the second depth.

We will now compare the results of the various plats which have all received both phosphate and ammonium salts, but which differed in their treatment as to other saline manures. Table 64 shows at a glance the mineral treatment of each plat, the estimated excess or deficiency of potash per acre as compared with plat 11 (calculated from known manurial additions and crop removals), the excess or deficiency of hydrochloric-acid-soluble potash found by analysis in the first 9 inches as compared with plat 11, and also the excess or deficiency of citric-acid-soluble potash, again as compared with plat 11, shown respectively in the first, second, and third depths of 9 inches each, and also in the total 27 inches which they comprise.

TABLE 64.—*Broadbalk wheat soils, samples collected in October, 1893—Plats 11, 12, 14, 13, 7, and 5.*

Plat.	Annual manuring.	Estimated excess or deficiency of potash per acre in soil after fifty years as compared with plat 11 (calculated from known additions and removals).	Excess of hydrochloric-acid-soluble potash per acre found by analysis in first 9 inches of soil as compared with plat 11.	Excess or deficiency of citric-acid-soluble potash per acre found by analysis as compared with plat 11.			
				First 9 inches.	Second 9 inches.	Third 9 inches.	27 inches.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
11	Phosphates and ammonium salts only						
12	Phosphates, ammonium, and sodium salts (some potassium salts in earlier years)	+ 20	+ 675	+ 21	+ 32	0	+ 53
14	Phosphates, ammonium, and magnesium salts (some potassium salts in earlier years)	− 92	+1,115	− 21	+ 53	+ 44	+ 76
13	Phosphates, ammonium, and potassium salts	+4,052	+1,971	+404	+288	+134	+ 826
7	Phosphates and ammonium, potassium, sodium, and magnesium salts	+3,662	+1,686	+519	+299	+ 78	+ 896
5	Phosphates and potassium, sodium, and magnesium salts (no nitrogen)	+5,242	+2,126	+716	+523	+156	+1,395

As far as the hydrochloric-acid results are concerned, we find a considerable increase in the potash dissolved from the surface soils of all the plats which have received alkaline manures, and the increase, as would naturally be expected, is very much greater in the case of the plats which have been constantly manured with potassium salts, and greatest of all on plat 5, in the case of which, owing to the absence of a manurial supply of nitrogen, the least demand has been made on the mineral contents of the soil. We do not, however, find in any case that, in the surface soil, hydrochloric acid yields as much as even one-half of the calculated acreage accumulation of potash.

We will now pass on to the citric-acid results.

Plat 12 is calculated to contain 20 pounds of potash per acre more than plat 11. The quantity found by citric acid in the surface soil is 21 pounds, with 32 pounds in the second depth, making an excess over plat 11 of 53 pounds per acre. This plat (plat 12) is even now much more fertile than plat 11, although the equivalent of the actual potash added has been nearly used up, and the potash in its produce is still annually far larger than in that of plat 11. There can be little doubt that the action of the sodium sulphate annually supplied keeps up a considerable annual supply of available potash.

Plat 13, with a full supply of potash, has, in fifty years, yielded about 4 per cent more grain and about 9 per cent more straw than plat 12; but its crops have contained 2,410 pounds of potash per acre, as against 1,743 pounds in those of plat 12. The potash-manured crops, therefore, while only from 4 per cent (grain) to 9 per cent (straw) larger, have contained nearly 40 per cent more potash.

One is somewhat tempted to draw the inference that, in the produce of the sodium sulphate plat (12), soda has partially replaced potash. In an elaborate study of the vegetative conditions and of the ash constituents of the mixed herbage of grass land, embodied in a recent paper by the late Sir John Lawes and Sir J. Henry Gilbert,[1] we are, however, warned against the temptation to assume that, even in adverse circumstances, soda can functionally take the place of potash. It is pointed out that, in defect of sufficient potash, more of soda or of lime, or of both, will be taken up—probably as carriers of nitric acid—and retained by the plant, but that the herbage will be more leafy and immature than where abundant potash is available. The free development of carbohydrates functionally demands the presence of an adequate quantity of potash; and, if the plant is stinted in potash, neither phosphates nor nitrates, even with the assistance of abundant soda and lime, can enable it to develop to its utmost. In the last six years of the fifty years now under review the annual produce of plat 13, with potassium sulphate, has exceeded that of plat 12 (with sodium sulphate) by 3¼ bushels of grain and 6½ hundredweight of straw. Both ripe grain and straw consist mainly of carbohydrates, and the excess virtually indicates the greater carbohydrate elaborative power conferred on the wheat plant by supplying it freely with potassium salts, and the inability of sodium salts to functionally replace them. But the output of potash from plat 12 in quite recent years is so much greater than from plat 11 without either potash or soda that there can be little doubt of the practical action of the sodium salts as a solvent of the soil potash.

Plat 14 is similar in every way in its history to plat 12, except that it has been annually dressed with 280 pounds of magnesium sulphate per acre instead of with 366½ pounds of sodium sulphate. Its yield, though less than that of plat 13, has been, on the average of fifty years, slightly better than that of plat 12, over half a bushel of grain and nearly 1 hundredweight of straw per acre being the annual advantage. In later years the inferiority to plat 13 has become more marked; but the superiority to plat 12 is still distinct, especially in the yield of straw. While receiving slightly less potash in its early dressings than plat 12, plat 14 has given in its crops nearly 100 pounds more potash in fifty years. There should, by calculation, be now a deficit of 92 pounds of potash per acre as compared with plat 11.

The surface soil of plat 14 yields much less citric-acid-soluble potash than was the case in 1881, but the second and third depths still maintain their superiority, leaving, as compared with plat 11, a balance to the good of 76 pounds per acre of easily soluble potash in the 27

[1] Philosophical Transactions of the Royal Society [England], series B, 1901, vol. 192, pp. 139-210.

inches of soil, as against a calculated deficiency, owing to cropping, of 92 pounds. From these facts, as well as from the higher output of potash from this plat, there seems to be little doubt that the magnesium sulphate, like the sodium sulphate, has acted as a potash solvent, but to an appreciably greater extent, especially in the subsoil.

We now pass on to plat 13, which has received, in addition to ammonium salts and superphosphate, a liberal annual dressing of potash far in excess of the demands of the crops. The excess of supply of potash per acre over the output of potash in the crops should leave the plat richer than plat 11 to the extent of 4,052 pounds per acre. We find soluble in dilute citric-acid solution in the 27 inches of soil an excess, as compared with plat 11, of 827 pounds. Of this quantity 404 pounds per acre is in the surface soil, 288 pounds in the second depth, and 134 pounds in the third depth, indicating a descent of the potassium salts. The citric-acid-soluble accumulation, even in the whole 27 inches, however, although so great, is not much more than 20 per cent of the expected accumulation. Either, therefore, much of the potash has been washed down to lower depths still, or it has "reverted" into some form of combination with the bases of the soil in which it fails to be dissolved by weak citric-acid solution.

Plat 7 is manured like plat 14, but has, in addition to potassium salts, received also an annual dressing of sodium and magnesium salts. This plat has on the average yielded $1\frac{1}{2}$ bushels more grain and $1\frac{5}{8}$ hundredweight more straw per acre than plat 13, while in the last six years (1889–1894) it gave $2\frac{3}{8}$ bushels more grain and $1\frac{7}{8}$ hundredweight more straw per acre. Its larger yield of crops has entailed a distinctly larger output of potash, so that the estimated excess in the soil (3,662 pounds per acre more than plat 11) is 390 pounds less than on plat 13. Citric acid dissolves, however, from this plat 115 pounds more potash per acre than in the case of plat 13 in the surface soil and 11 pounds more in the second 9 inches, but 56 pounds less in the third 9 inches, leaving a balance of 70 pounds per acre in favor of plat 7 in the whole 27 inches. On the whole, and mainly in the surface soil, it would seem that the magnesium and sodium salts have effected the retention of considerably more of the potash in an easily soluble condition.

Plat 5 is a duplicate of plat 7, with, however, the important exception that it has received no nitrogenous manure whatever. It yields but meager crops—better, it is true, than those of the wholly unmanured plat—even now after fifty years. It has given less than half the quantity of grain yielded by plat 7 and about three-eighths of the straw. Its estimated excess of potash as compared with plat 11 is 5,242 pounds per acre, or 1,580 pounds more than plat 7. The surface soil is richer in citric-acid-soluble potash than that of plat 7 by 203 pounds per acre, the second 9 inches by 225 pounds, and the third

9 inches by 78 pounds, making in the 27 inches just over 500 pounds per acre, or nearly one-third of the estimated difference.

We have yet to consider the two farmyard-manured plats 2b and 2a, the former of which has received continuously throughout the experiments 14 tons of dung per acre per annum, while the latter has been similarly treated since 1884 only, having been previously unmanured. An examination of the results yields the following data:

TABLE 65.—*Broadbalk wheat soils, samples collected in October, 1893—Plats 2b and 2a.*

	Plat 2b (dunged for 50 years).	Plat 2a (dunged for 9 years; unmanured for preceding 41 years).
	Pounds.	*Pounds.*
Estimated excess of potash per acre as compared with plat 3	10,043	1,790
Excess of potash over that in plat 3, found soluble in strong hydrochloric acid in first 9 inches	948	1,249
Excess of potash over that in plat 3, found soluble in 1 per cent citric-acid solution in—		
First 9 inches	813	746
Second 9 inches	577	289
Third 9 inches	156	67
27 inches	1,546	1,102

It will be seen that, in the case of the continuously dunged plat, only a very small proportion of the estimated excess of potash is found by analysis, either by hydrochloric-acid extraction or by citric-acid extraction. The proportion of potash in the dung is put by Sir Henry Gilbert at 0.75 per cent. The difficulty of forming an accurate estimate of the average constituents of so variable a substance as dung has already been discussed in relation to phosphoric acid, and I can not help being inclined to think that the average richness of the dung in potash may have been overestimated. An average error of 0.1 per cent in the estimate would amount to 1,570 pounds per acre in fifty years, and an error of 0.25 per cent to no less than 3,920 pounds per acre.

But even after making a liberal allowance for this, there is clearly a large proportion of potash not accounted for in the citric-acid-soluble contents of the soil, which must either have remained in or reverted into an insoluble condition, or have descended still lower into the subsoil. It seems probable that both suppositions are true, for there is certainly, in 1893, clear evidence of accumulated potash as far down as the third depth.

In the case of plat 2a, which has only been dunged in recent years, the analytical figures accord much better with the estimate, and it is obvious that whatever error there may be in the potash estimate for the dung has only been multiplied ninefold instead of fifty fold; and it is therefore possible that the estimate adopted may be more accurate for the dung recently used than for that of earlier years. There seems to be evidence here again that the potash of the dung travels downward with considerable facility, for, although the dunging has only been continued for nine years, there is a great increase in the citric-acid-soluble potash of the second 9 inches, and a considerable increase in that found in the third 9 inches.

Potash in Drainage Waters.

Reference has already been made to the results of analyses of the drainage waters of Broadbalk field made in 1867, 1868, and 1869 by the late Dr. Augustus Voelcker.

Averaging the results of the potash determinations in the various samples analyzed during these years, we obtain the following figures:

Table 66.—*From analyses of Broadbalk field drainage waters made by the late Dr. Augustus Voelcker, F. R. S., 1866–1869.*

[Parts per million.]

Plat.	Annual manuring.	Average quantity of potash in drainage water.
3 and 4	Unmanured	1.7
10	Ammonium salts only	1.9
11	Ammonium salts and superphosphate	1
12	Ammonium salts, superphosphate, and sodium sulphate	2.7
14	Ammonium salts, superphosphate, and magnesium sulphate	1
13	Ammonium salts, superphosphate, and potassium sulphate	3.3
7	Ammonium salts and full mineral dressing	2.9
5	Full mineral dressing without nitrogen	5.4
2	Farmyard manure	5.4

These results, although the samples were few, accord very well with what might be expected. The potash in the drainage water from plat 11 (supplied with phosphates and nitrogen, but no potash) is less than in that from the unmanured plats, 3 and 4, or from plat 10, which received only ammonium salts, the utilization by the crops being, of course, greater on plat 11 in presence of an abundant supply of phosphates and nitrogen.

Plat 12, supplied in its earlier history with potash, and, in virtue of this (and probably also of the solvent action of the sodium salts), showing, in the 1865 soil samples, more citric-acid-soluble potash than plat 11, also yields more potash in its drainage water, and it also yields more than plat 14, to which magnesium salts were applied, which is again in accord with the citric-acid results.

Plat 13, well supplied with potash, shows decidedly more potash in its drainage water than plat 7, which, while also liberally supplied with potash, gets in addition, sodium and magnesium salts, and gives in consequence a greater crop, utilizing somewhat more potash.

Plat 5, getting a fuller supply of minerals than plat 13, but no nitrogen, yields much more potash in its drainage—as much as the dunged plat, which receives the greatest quantity of potash.

The average quantities are in no case great, varying from 1 part of potash per million parts of water on plats 11 and 14, to 5.4 parts per million on plats 5 and 2; but the higher quantities are nevertheless significant. Assuming an annual percolation of 10 inches of drainage water into the drainpipes or into the subsoil below 27 inches, the quantities found would probably represent as little as about 2½ pounds of potash per acre per annum in the case of plats 11 and 14, and as much as 12½ pounds per acre from plat 5 (full mineral dressing without nitrogen) and from plat 2 (continuously dunged). The difference between these two extremes would amount to 500 pounds per acre in fifty years, but it seems probable that, as the quantity of potassium salts has annually accumulated in the soil, the quantity of potash in the drainage waters will have become greater in later years on the potash-manured plats and on the continuously dunged plats. Dr. Voelcker's analyses, therefore, may be regarded as yielding, even as long ago as 1867–1869, evidence of appreciable descent of potash on the plat on which the application of potassium salts had been excessive, and where its utilization had been least, owing to the absence of nitrogenous manure, and also on the continuously dunged plat. Furthermore, the analytical results of the subsoils of these plats down to a depth of 27 inches show a much larger quantity of citric-acid-soluble potash than do those of any of the other plats, and this seems to accord with the indications of the descent of some potash in the drainage water to even a lower depth.

General Conclusions as to Potash.

The general conclusions derived from the potash results, as summed up in the paper recently laid before the Royal Society,[1] are to the effect that strong hydrochloric acid, as a solvent for potash in soil analysis, is again shown to be practically useless as a gauge of potash fertility, especially in soils containing an abundance of total potash in mineral combination as silicates, etc. No concordant results are obtainable except by working under the strictest arbitrary conditions, and the results, even when concordant, have little meaning apart from an independent knowledge of the history of the soil. With this knowledge they are interesting, but in its absence they are of little use except in extreme cases.

The results obtained by citric acid, however, are on the whole both instructive and consistent. They show that the largest accumulation of manurial potash, where applied in the form of dung or of potassium salts, is in the surface soil; but that a large proportion is also found

[1] Philosophical Transactions of the Royal Society [England], 1901, series B, vol. 194, pp. 235–290.

in the second, and even in the third, 9 inches. The accumulation in the subsoil is most evident in the cases of the dunged plats and of the plat which, in addition to potassium salts, has received superphosphate and mixed sodium and magnesium sulphates, without nitrogen. Both sodium and magnesium salts have exercised a distinct influence in increasing the proportion of citric-acid-soluble potash in all depths on the plats to which no potassium salts have been applied for forty years. These plats still maintain a higher yield of potash in their crops than does the plat manured with superphosphate and ammonium salts only, though the equivalent of the potash originally added has been more than exhausted in one case and nearly exhausted in the other. Furthermore, sodium and magnesium salts, used in conjunction with potash salts, have caused a much larger retention of potash in a citric-acid-soluble condition than when potassium sulphate has been used without them, although the potash taken up by the crops has been greater than in the latter case.

It has usually been considered that potash is pretty firmly retained in the surface soil on land containing a fair proportion of clay. That this is the case, as compared with sodium salts, has often been shown, and, apart from earlier investigation, was clearly brought out in the drainage water analyses of the late Dr. Voelcker, just referred to; but, as we have seen, even these analyses showed a considerable loss of potash in drainage in certain cases, and it is evident from the results of the analyses of the soils and subsoils that though, relatively to sodium salts, potassium salts readily become fixed in clay soils—often, probably, passing into a very stable insoluble form—they are nevertheless far more "migratory" than phosphoric acid.

SECTION III.

THE BROADBALK WHEAT SOILS (Continued).

COMPARISON OF RESULTS OF ANALYSES OF THE VARIOUS SAMPLES DRAWN, RESPECTIVELY, IN 1865, 1881, AND 1893.

TOTAL NITROGEN AND ORGANIC CARBON.

We have complete sets of nitrogen determinations in the samples of 1881 as well as in those of 1893, and also nitrogen determinations in the less complete set taken in 1865.

It will be remembered (see earlier discussion, p. 25) that, in discussing the 1893 samples, we have adopted, as probably the more correct, the results of the nitrogen determinations made by the Kjeldahl method; but, for comparison with the earlier results, we must take for the 1893 samples the determinations made by the soda-lime method, as these alone will be strictly comparable with the figures similarly obtained for the 1865 and 1881 samples. The deficiencies should be fairly constant at all three periods, and should not materially affect the differential results.

We also have organic carbon determinations in two out of the three sets of samples.

Tables 67 and 68 set forth both the nitrogen and carbon results, stated in terms of percentage and as pounds per acre based upon the adopted weights of soil already explained.

TABLE 67.—*Broadbalk wheat soils—Total* NITROGEN (*by soda-lime method*), *stated as percentages of fine dry soil and as pounds per acre, in samples collected October, 1865, October, 1881, and October, 1893.*

FIRST 9 INCHES.

	1865.		1881.		1893.	
	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
Plat 2a	....	....	....	....	0.1520	3,815
Plat 2b	0.1752	4,343	0.1836	4,399	.2132	4,976
Plat 3	.1050	2,722	.1009	2,616	.0940	2,437
Plat 4	....	....	.0919	2,383	.0906	2,349
Plat 5	.1073	2,782	.0981	2,543	.0971	2,517
Plat 6	....	....	.1106	2,867	.1076	2,790
Plat 7	.1170	3,034	.1207	3,129	.1146	2,971
Plat 8	....	....	.1260	3,267	.1167	3,026
Plat 9a	.1178	3,054	.1200	3,111	.1116	2,893
Plat 9b	....	....	.1064	2,759	.1058	2,743
Plat 10a	.1065	2,761	.1034	2,681	.1002	2,598
Plat 10b	....	....	.1037	2,689	.1029	2,668
Plat 11	.1125	2,916	.1121	2,906	.1119	2,901
Plat 12	.1157	2,999	.1155	2,994	.1110	2,878
Plat 13	.1151	2,984	.1191	3,088	.1088	2,821
Plat 14	.1154	2,991	.1163	3,015	.1204	3,122
Plat 15	....	....	.1178	3,054	.1188	3,080
Plat 16	.1210	3,137	.1066	2,764	.1110	2,878
Plat 17	....	....	.1088	2,821	.1117	2,896
Plat 18	....	....	.1116	2,893	.1204	3,122
Plat 19	....	....	.1230	3,186	.1309	3,377

TABLE 67.—*Broadbalk wheat soils*—Continued.

SECOND 9 INCHES.

	1865.		1881.		1893.	
	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
Plat 2a					0.0761	2,033
Plat 2b	0.0810	2,164	0.0742	1,982	.0712	1,902
Plat 3	.0738	1,971	.0681	1,819	.0696	1,859
Plat 4			.0644	1,720	.0670	1,790
Plat 5	.0715	1,910	.0698	1,865	.0684	1,827
Plat 6			.0684	1,827	.0671	1,792
Plat 7	.0707	1,889	.0692	1,849	.0598	1,597
Plat 8			.0718	1,918	.0696	1,859
Plat 9a	.0757	2,022	.0717	1,915	.0765	2,044
Plat 9b			.0689	1,841	.0778	2,078
Plat 10a	.0730	1,950	.0672	1,795	.0789	2,108
Plat 10b			.0681	1,819	.0765	2,044
Plat 11	.0762	2,036	.0736	1,966	.0747	1,995
Plat 12	.0758	2,025	.0729	1,947	.0791	2,113
Plat 13	.0722	1,929	.0707	1,889	.0686	1,833
Plat 14	.0814	2,174	.0695	1,857	.0748	1,998
Plat 15			.0711	1,899	.0809	2,161
Plat 16	.0786	2,100	.0654	1,747	.0708	1,891
Plat 17			.0721	1,926	.0731	1,953
Plat 18			.0743	1,985	.0701	1,873
Plat 19			.0797	2,129	.0776	2,073

THIRD 9 INCHES.

	1865.		1881.		1893.	
	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
Plat 2a					0.0645	1,801
Plat 2b	0.0619	1,728	0.0576	1,608	.0628	1,753
Plat 3	.0561	1,566	.0550	1,535	.0594	1,658
Plat 4			.0563	1,572	.0573	1,600
Plat 5	.0612	1,708	.0572	1,597	.0560	1,563
Plat 6			.0557	1,555	.0558	1,558
Plat 7	.0613	1,711	.0563	1,572	.0527	1,471
Plat 8			.0606	1,692	.0587	1,639
Plat 9a	.0620	1,731	.0603	1,683	.0609	1,700
Plat 9b			.0568	1,586	.0649	1,812
Plat 10a	.0637	1,778	.0574	1,602	.0678	1,893
Plat 10b			.0620	1,731	.0682	1,904
Plat 11	.0613	1,711	.0617	1,722	.0622	1,736
Plat 12	.0627	1,750	.0618	1,725	.0676	1,887
Plat 13	.0584	1,630	.0566	1,580	.0566	1,580
Plat 14	.0637	1,778	.0607	1,694	.0635	1,773
Plat 15			.0612	1,708	.0578	1,613
Plat 16	.0620	1,731	.0604	1,686	.0606	1,692
Plat 17			.0629	1,756	.0606	1,692
Plat 18			.0596	1,664	.0606	1,692
Plat 19			.0639	1,784	.0697	1,946

TABLE 68.—*Broadbalk wheat soils—Organic* CARBON, *stated as percentages of fine dry soil and as pounds per acre, in samples collected October, 1881, and October, 1893.*

	First 9 inches.				Second 9 inches.				Third 9 inches.			
	1881.		1893.		1881.		1893.		1881.		1893.	
	Per cent.	Pounds per acre	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
Plat 2a	......	....	1.582	39,711	......	....	0.645	17,230	....	....	0.515	14,376
Plat 2b	2.132	51,082	2.230	52,046	0.674	18,005	.748	19,981	0.519	14,488	.492	13,734
Plat 3	.977	25,330	.888	23,022	.612	16.348	.565	15,093	.468	13,064	.483	13,483
Plat 4	1.010	26,185	.909	23,567	.567	15,146	.600	16,028	.463	12,925	.463	12,925
Plat 5	1.033	26,782	.931	24,137	.609	16,268	.587	15,681	.466	13,008	.446	12,450
Plat 6	1.190	30,852	1.019	26,419	.606	16.188	.583	15,574	.448	12,506	.429	11,976
Plat 7	1.267	32,849	1.101	28,545	.599	16,001	.530	14,158	.450	12,562	.426	11,892
Plat 8	1.312	34,015	1.138	29,504	.646	17,257	.608	16,242	.470	13,120	.443	12,366
Plat 9a	1.250	32,408	1.162	30,126	.655	17,497	.651	17,390	.463	12,925	.535	14,935
Plat 9b	1.145	29,686	1.008	26,134	.608	16,242	.640	17,096	.453	12,645	.524	14,627
Plat 10a	1.095	28,389	1.049	27,197	.620	16.562	.668	17,844	.476	13,288	.526	14,683
Plat 10b	1.058	27,430	.969	25,122	.648	17.310	.656	17,524	.521	14,544	.524	14,627
Plat 11	1.176	30,489	1.107	28,700	.694	18,539	.643	17,177	.503	14,041	.492	13,734
Plat 12	1.285	33.315	1.123	29,115	.672	17.951	.643	17,177	.501	13.985	.526	14,683
Plat 13	1.257	32,589	1.165	30,204	.664	17.738	.630	16,829	.481	13,427	.477	13,315
Plat 14	1.254	32.511	1.137	29,478	.641	17,123	.629	16,803	.493	13,762	.502	14,013
Plat 15	1.246	32,304	1.170	30,334	.664	17,738	.727	19,421	.482	13,455	.535	14,935
Plat 16	1.080	28,000	1.065	27,611	.588	15,707	.682	18,218	.484	13,511	.438	12,227
Plat 17	1.210	31,371	1.094	28,363	.642	17,150	.650	17,364	.479	13,371	.492	13,734
Plat 18	1.261	32,693	1.146	29.711	.638	17,043	.630	16,829	.442	12,338	.478	13,343
Plat 19	1.367	35,406	1.257	32,430	.717	19,153	.719	19,207	.504	14,069	.587	16,386

Attention for the moment may be directed especially to the surface soils, representing the first 9 inches of each plat, in each of the three years.

Having devoted so much time and space to the detailed consideration of the 1893 samples, all we need here do is to see how far the results of the two previous samplings bear out the conclusions generally arrived at from those of later ones. You may be reminded that the three samplings represent the twenty-second, thirty-eighth, and fiftieth years of these continuous experiments. The continuously dunged plat, 2b, shows a steady gain in percentage of nitrogen, which has increased markedly since 1881, the three percentages being 0.1752, 0.1836, and 0.2132. Between 1865 and 1881 the difference, expressed as pounds per acre, is less marked than in percentage, but this is because the surface soil has become lightened and weighs less for a like depth. The organic carbon, between 1881 and 1893, shows an increase of 964 pounds per acre.

The rape-cake plat (No. 19) was not analyzed in 1865. Between 1881 and 1893, however, we see that it has accumulated 0.0079 per cent of nitrogen, or 191 pounds per acre. The farmyard manure and the rape-cake plats, it will be remembered, are the only plats that seem to accumulate actual manurial nitrogenous matter as such.

Next we may consider plats 3 and 4, the unmanured plats. Both show a steady decline in nitrogen and carbon from period to period. Closely behind them, both in nitrogen and carbon diminution, comes plat 5, with mineral dressings only. It has lost rather less nitrogen than plats 3 and 4, but the loss has been progressive, though the diminution seems to have been slower latterly than in earlier years.

Plats 10a and 10b, notwithstanding their 400 pounds per acre per annum of ammonium salts, show, in the absence of mineral manures, a gradual but steady loss of soil nitrogen, and the carbon also decreases.

Plats 6, 7, and 8, all supplied with full minerals, but progressively increasing dressings of ammonium salts (200, 400, and 600 pounds per acre per annum respectively), all show a decrease of nitrogen since 1881, and the carbon also declines.

Plats 11, 12, 13, and 14, the series which all receive the same dressing of ammonium salts (400 pounds per acre per annum) and superphosphate, but differ in other saline applications, show on the whole a decline in both carbon and nitrogen.

Plat 9a, manured with sodium nitrate and full minerals, shows a decrease in both carbon and nitrogen. It is to be noted that its neighbor, plat 9b, which receives only sodium nitrate, without minerals, was in 1881, as well as in 1893, much poorer both in nitrogen and carbon than plat 9a, which receives phosphates and potash, as well as sodium nitrate, and which, in consequence, persistently grows larger crops, necessarily leaving larger root and stubble residues.

Plat 16 shows well the evidences of its checkered history. Liberally manured from 1852 to 1864, with full minerals and as many as 800 pounds of ammonium salts per annum, it was in 1865 the richest of all the chemically manured plats as regards nitrogen contents, showing as much as 0.1210 per cent of nitrogen. Then it was unmanured for nineteen years, and toward the close of these starvation years, in 1881, we find it to have fallen in nitrogen contents to 0.1066 per cent, a decline of 373 pounds per acre in sixteen years, or 23 pounds per annum. Since 1884, however, it has had full minerals and 550 pounds per annum of sodium nitrate, and after these nine years of prosperity it shows, in 1893, a regain of 114 pounds per acre of its lost nitrogen.

Plats 17 and 18, nitrogenously and minerally manured in alternate years, and giving alternately high and low crops, are still gaining nitrogen, not having apparently reached the turning point in accumulation shown much earlier on most of the chemically manured plats.

The following table (Table 69) shows conveniently, together with the surface-soil nitrogen contents of the various plats already given, the gain and loss indicated by the samples during each period, and also the difference at each date between each plat and plat 5, the plat fully supplied with minerals, but without any nitrogenous dressing, and therefore the plat in the best position to utilize soil nitrogen, and on this, and also on other grounds, the best standard of comparison for many of the plats.

TABLE 69.—*Broadbalk wheat soils (1865, 1881, and 1893)—First 9 inches only—* NITROGEN *per acre in fine dry soil, and differences for each period; also the amounts, + or −, plat 5.*

Plat.	Annual manuring.	Nitrogen per acre in fine dry soil.							
		1865.	1881.	1893.	1881, + or − 1865.	1893, + or − 1881.	+ or −, plat 5. 1865.	1881.	1893.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
2a	Farmyard manure since 1884	......	......	3,815	....	....	....	....	+1,298
2b	Farmyard manure, 50 years	4,343	4,399	4,976	+ 56	+577	+1,561	+1,856	+2,459
3	Unmanured	2,722	2,616	2,437	−106	−179	− 60	+ 73	− 80
4	Unmanured since 1852	......	2,383	2,349	....	− 34	....	− 160	− 168
5	Full minerals	2,782	2,543	2,517	−239	− 26	....	....	....
6	Full minerals and ammonium salts	......	2,867	2,790	....	− 77	....	+ 324	+ 273
7	do	3,034	3,129	2,971	+ 95	−158	+ 252	+ 586	+ 454
8	do	......	3,267	3,026	....	−241	....	+ 724	+ 509
9a	Full minerals and sodium nitrate	3,054	3,111	2,893	+ 57	−218	+ 272	+ 568	+ 376
9b	Sodium nitrate only	......	2,759	2,743	....	− 16	....	+ 216	+ 226
10a	Ammonium salts (no minerals since 1844)	2,761	2,681	2,598	− 80	− 83	− 21	+ 138	+ 81
10b	Ammonium salts (no minerals since 1850)	......	2,689	2,668	....	− 21	....	+ 146	+ 151
11	Phosphates and ammonium salts	2,916	2,906	2,901	− 10	− 5	+ 134	+ 363	+ 384
12	Phosphates, sodium, and ammonium salts	2,999	2,994	2,878	− 5	−116	+ 217	+ 451	+ 361
13	Phosphates, potassium, and ammonium salts	2,984	3,088	2,821	+104	−267	+ 202	+ 545	+ 304
14	Phosphates, magnesium, and ammonium salts	2,991	3,015	3,122	+ 24	+107	+ 209	+ 472	+ 605
15	Full minerals and ammonium salts (autumn)	......	3,054	3,080	....	+ 26	....	+ 511	+ 563
16	Full minerals and sodium nitrate since 1884 (1865–1883 unmanured)	3,137	2,764	2,878	−373	+114	+ 355	+ 221	+ 361
17	Full minerals and ammonium salts, transposed in alternate years	......	2,821	2,896	....	+ 75	....	+ 278	+ 379
18	(same as 17)	......	2,893	3,122	....	+229	....	+ 350	+ 605
19	Rape cake	......	3,186	3,377	....	+191	....	+ 643	+ 860

Generally we see that on the chemical plats the tendency, even under liberal treatment, has been toward decline rather than increase of accumulated nitrogen in later years, following on an earlier period of gain. In fact, we seem to see in progress the attainment of that equilibrium which Professor Warington pointed out to you in 1891 as naturally tending to establish itself under any manurial conditions in a drained and aerated soil. Up to a certain point the increase of crop and weed residue, induced by liberal manuring, produces accumulation of organic matter; but this increase furnishes increased pabulum for the myriads of soil microbes, fostering their growth and increasing their activity, so that they destroy the excess of organic matter that helped them to multiply. They then become less active, and a balance is struck between the annual supply of organic food furnished to them by crop and root residues and their annual potency to break it down and destroy it. On such an explanation each plat should in time arrive at its own point of average equilibrium as regards nitrogen contents.

On this supposition it may be said that on plat 3 (unmanured for fifty years) the conditions are less favorable for bacterial multiplication and exercise of function; hence the slowness of soil nitrification which, aided by the absence of mineral manure, keeps the crops on this plat small, but at the same time renders their decline so remarkably slow that even after more than half a century of ceaseless cropping, the land still yields from 12 to 13 bushels of grain and its accompanying straw per acre.

The results for the subsoils are more difficult to consider, owing to the natural irregularities formerly alluded to. It may, however, be said that, in the second depth, from 1865 to 1881 there appears throughout to be a diminution of nitrogen, wherever we have 1865 samples for purposes of comparison. Between 1881 and 1893 the general tendency appears to be toward an increase in nitrogen. In the third 9 inches, from 1865 to 1881 there appears to be more or less decline, with a tendency toward increase between 1881 and 1893. But many of the differences are only such as may, so far from the surface, be due to chance irregularities.

NITROGEN AS NITRATES—"NITRIC" NITROGEN (1881 AND 1893 RESULTS COMPARED).

The nitric nitrogen was not determined in 1865, but it was determined in the 1881 samples by Professor Warington. The following table shows, side by side, the nitric nitrogen found in the first three depths of each plat in both years, and also a summary giving for each year the total quantity found in the whole 27 inches.

TABLE 70.—*Broadbalk wheat soils, 1881 and 1893.*—NITROGEN *as* NITRATES (*"nitric" nitrogen*) *stated as parts per million of fine dry soil and as pounds per acre, in samples collected in October, 1881, and October, 1893.*

Plat.	First 9 inches.				Second 9 inches.				Third 9 inches.			
	1881.		1893.		1881.		1893.		1881.		1893.	
	Parts per million.	Pounds per acre.	Parts per million.	Pounds per acre.	Parts per million.	Pounds per acre.	Parts per million.	Pounds per acre.	Parts per million.	Pounds per acre.	Parts per million.	Pounds per acre.
2a	......	......	9.43	23.67	......	......	8.48	22.65	......	......	3.68	10.27
2b	12.23	29.30	4.51	10.53	5.70	15.23	16.98	45.36	2.45	6.84	4.39	12.25
3	3.80	9.85	3.72	9.64	1.94	5.18	3.45	9.22	1.00	2.79	.98	2.74
4	3.62	9.39	3.07	7.96	1.48	3.95	2.63	7.03	.65	1.81	.76	2.12
5	4.94	12.81	4.06	10.53	2.63	7.03	2.38	6.36	1.67	4.66	.80	2.23
6	6.46	16.75	5.45	14.13	2.77	7.40	4.77	12.74	1.71	4.77	2.08	5.81
7	7.94	20.59	5.77	14.96	4.17	11.14	7.19	19.21	2.07	5.78	3.06	8.54
8	8.27	21.44	6.71	17.40	5.15	13.76	10.92	29.17	2.83	7.90	3.12	8.71
9a	7.73	20.04	6.41	16.62	3.69	9.86	7.20	19.23	2.98	8.32	2.40	6.70
9b	6.38	16.54	4.28	11.10	7.43	19.85	13.05	34.86	6.44	17.98	5.58	15.58
10a	5.55	14.39	4.83	12.52	4.38	11.70	9.52	25.43	2.65	7.40	4.03	11.25
10b	5.26	13.64	3.64	9.44	3.32	8.87	10.88	29.06	2.15	6.00	5.01	13.99
11	7.03	18.23	4.50	11.67	3.42	9.14	9.20	24.58	1.32	3.68	5.33	14.88
12	5.99	15.53	5.46	14.16	3.81	10.18	9.54	25.48	1.58	4.41	4.35	12.14
13	4.94	12.81	5.37	13.92	3.30	8.82	9.79	26.15	.93	2.60	3.38	9.44
14	6.30	16.33	5.16	13.38	3.21	8.57	11.60	30.99	1.31	3.66	4.22	11.78
15	5.26	13.64	3.86	10.01	3.95	10.55	7.00	18.70	1.50	4.19	3.77	10.52
16	4.15	10.76	5.24	13.59	1.86	4.97	15.94	42.58	5.11	14.26	7.44	20.77
17	4.19	10.86	4.70	12.19	2.76	7.37	10.37	27.70	1.24	3.46	3.06	8.54
18	4.46	11.56	4.49	11.64	3.10	8.28	15.53	41.49	1.90	5.30	2.29	6.39
19	5.52	14.30	8.55	22.06	4.79	12.80	9.12	24.36	2.58	7.20	5.08	14.18

TABLE 70.—*Broadbalk wheat soils, etc.*—Continued.

SUMMARY—FIRST, SECOND, AND THIRD DEPTHS (27 INCHES).

Plat.	Annual manuring.	Nitrogen in manure per acre per annum.	1881.	1893.
		Pounds.	*Pounds.*	*Pounds.*
2a	Farmyard manure since 1884	200	....	56.59
2b	Farmyard manure 50 years	200	51.37	68.14
3	Unmanured	0	17.82	21.60
4	Unmanured since 1852	0	15.15	17.11
5	Full minerals	0	24.50	19.12
6	Full minerals and ammonium salts	43	28.92	32.68
7	.... do	86	37.51	42.71
8	.... do	129	43.10	55.28
9a	Full minerals and sodium nitrate	43	38.22	42.55
9b	Sodium nitrate only	43	54.37	61.54
10a	Ammonium salts (no minerals since 1844)	86	33.49	49.20
10b	Ammonium salts (no minerals since 1850)	86	28.51	52.49
11	Phosphates and ammonium salts	86	31.05	51.13
12	Phosphates, sodium, and ammonium salts	86	30.12	51.78
13	Phosphates, potassium, and ammonium salts	86	24.23	49.51
14	Phosphates, magnesium, and ammonium salts	86	28.56	56.15
15	Full minerals and ammonium salts (autumn)	86	28.38	39.23
16	Full minerals and sodium nitrate since 1884	86	*a* 29.99	76.94
17	Full minerals and ammonium salts transposed in alternate years	86	21.69	48.43
18			25.14	59.52
19	Rape cake	93	34.30	60.60

a No nitrate in 1881.

The climatic conditions in the two years were by no means alike, except in so far as that in both years they resulted in the crops being exceptionally light. In 1881 there was exceedingly heavy rain immediately after the crop was cut in August, amounting to nearly 6 inches; and this rain must have for the most part washed downward the nitrates already existing in the upper layers of the soil and unutilized by the crop. Indeed (as was pointed out in Professor Warington's lectures to you in 1891), the analyses of drainage waters collected from the plats at the time showed that this was the case. The field was plowed in September, and the moisture, warmth, and aeration of the soil produced exceedingly rapid autumn nitrification before the soils were sampled in October. The progress of this nitrification was most interestingly shown in the successive samples of drainage water examined during the period.[1]

It seems probable, then, that the greater part of the nitrates found in the first and second depths in 1881 was due to nitrification occurring subsequently to harvest.

In 1893 there had been a spring and summer drought, most unfavorable for early nitrification. Between harvest and soil sampling there was, however, as we have seen when discussing the 1893 results, 4½ inches of rain, and three-fourths inch more during the time of sampling, with the result that much of the nitrates existing unused at harvest must have been washed into the second depth. But the wash-

[1] Professor Warington's Lectures, U. S. Dept. Agr., Office of Experiment Stations Bul. 8, p. 85.

ing downward of the nitrates could not have occurred to anything like so great an extent as in 1881. On the other hand, the moisture after harvest, as in 1881, must have aided autumn nitrification, though not to so great an extent.

The result of the difference between the two seasons is that, on the whole, we find in October, in 1893, a much larger quantity of nitrates than in the same month in 1881. For example, if we take the continuously dunged plat, 2b, we find in the three depths (27 inches) about 68 pounds of nitric nitrogen per acre in 1893, as against about 51 pounds in 1881. So, also, in the rape-cake plat we find over 60 pounds per acre in 1893 and only about 34 pounds in 1881. On the unmanured plats, 3 and 4, and on plat 5, which is manured with minerals only, we find but little difference, the production of nitrates on these plats being, it will be remembered, at a minimum, there being no manurial nitrogen to yield nitrates, but only the natural-soil nitrogen reenforced by meager crop residues. It may be noticed, however, that while plats 3 and 4, under the conditions of the 1893 season, showed in 27 inches only about the same quantity of nitric nitrogen as plat 5, yet the last named plat in 1881 showed considerably more than the two unmanured plats, indicating, in the more favorable nitrifying conditions, the effects of its greater stock of crop residues owing to its greater average fertility.

Plats 9a and 9b receive sodium nitrate yearly—in the case of 9a with full minerals in addition, but in the case of 9b without them. In 1881 the quantity of sodium nitrate applied was 550 pounds per acre per annum, but in 1893 it was only 275 pounds. Nevertheless, in 1881, after the heavy rain, the total quantity of nitric nitrogen found on both plats down to 27 inches was less than in 1893 after the much lighter dressing. In both years, however, we find that in the second and third depths the quantity of nitrate left is much less on plat 9a, which receives mineral dressings and gives larger crops, than on plat 9b, which, getting the same quantity of sodium nitrate but no minerals, gives a smaller annual produce.

Plats 10, 11, 12, 13, and 14, all dressed alike in both years with ammonium salts, with and without various mineral additions, all showed in the total 27 inches much less nitric nitrogen in 1881 than in 1893, again indicating that the washing down of the nitrates formed from the ammonium salts was in 1881 much more complete than in the season of 1893.

A very marked difference will be noticed in the nitrogen found at the two different periods on plat 16. Plat 16, in 27 inches, showed only 30 pounds of nitric nitrogen per acre per annum in 1881, as against 77 pounds in 1893; but in 1881 this plat was, and had been for nineteen years, unmanured, while in 1893 it had for ten years been receiving a full mineral dressing, including 550 pounds per acre per annum of sodium nitrate. The difference is mainly shown in the second and third depths.

CHLORIN (1881 AND 1893 RESULTS COMPARED).

The chlorin was not determined in 1865, but was determined by Professor Warington in the samples of the first, second, and third depths collected in 1881, and the results, which have not been previously published, are shown in the following table, side by side with those of the 1893 samples:

TABLE 71.—*Broadbalk wheat soils, 1881 and 1893*—CHLORIN *stated as parts per million of fine dry soil and as pounds per acre, in samples collected in October, 1881, and October, 1893.*

Plat.	First 9 inches.				Second 9 inches.				Third 9 inches.			
	1881.		1893.		1881.		1893.		1881.		1893.	
	Parts per million.	Pounds per acre.	Parts per million.	Pounds per acre.	Parts per million.	Pounds per acre.	Parts per million	Pounds per acre.	Parts per million.	Pounds per acre.	Parts per million.	Pounds per acre.
2a	......	......	9.77	24.52	......	......	9.80	26.18	......	......	8.01	22.36
2b	5.27	12.63	14.74	34.40	9.43	25.19	13.49	36.04	7.17	20.02	5.57	15.55
3	3.26	8.45	3.90	10.11	5.29	14.13	6.33	16.91	6.92	19.32	4.05	11.31
4	3.49	9.05	3.28	8.50	5.11	13.65	6.83	18.25	3.97	11.08	5.23	14.60
5	3.30	8.56	6.36	16.49	9.26	24.74	7.69	20.54	10.82	30.20	4.96	13.85
6	3.64	9.44	5.75	14.91	12.36	33.02	10.11	27.01	13.27	37.04	6.20	17.31
7	6.00	15.56	5.54	14.36	18.11	48.38	10.05	26.85	15.72	43.88	7.75	21.63
8	4.64	12.03	4.91	12.73	30.49	81.45	13.10	34.99	33.06	92.29	9.28	25.91
9a	4.88	12.65	0.72	1.87	11.11	29.68	8.37	22.36	12.96	36.18	5.88	16.41
9b	4.81	12.47	2.47	6.40	10.90	29.12	7.20	19.23	10.48	29.25	7.88	22.00
10a	5.23	13.56	6.69	17.34	22.43	59.92	11.98	32.00	20.93	58.43	8.71	24.31
10b	9.56	24.79	1.44	3.73	21.55	57.57	11.08	29.60	19.66	54.88	9.41	26.27
11	7.85	20.35	3.49	9.05	13.24	35.37	9.88	26.39	13.36	37.29	8.31	23.20
12	9.49	24.60	4.32	11.20	16.22	43.33	10.95	29.25	22.59	63.06	8.89	24.82
13	4.70	12.19	5.25	13.61	12.22	32.64	16.60	44.34	18.32	51.14	8.30	23.17
14	9.73	25.23	3.82	9.90	15.82	42.26	13.04	34.83	18.09	50.50	10.43	29.12
15	7.83	20.30	2.88	7.47	11.27	30.11	11.74	31.36	10.39	29.00	13.34	37.24
16	7.56	19.60	2.57	6.66	5.77	15.41	7.18	19.18	......	......	7.12	19.88
17	8.10	21.00	2.46	6.38	6.75	18.03	7.75	20.70	8.18	22.83	7.76	21.66
18	6.51	16.88	4.00	10.37	19.75	52.76	13.32	35.58	18.39	51.34	9.13	25.49
19	3.43	8.88	4.52	11.66	5.35	14.29	7.46	19.93	5.44	15.19	12.45	34.75

SUMMARY FIRST, SECOND, AND THIRD DEPTHS (27 INCHES).

Plat.	Annual manuring.	Nitrogen in manure per acre per annum.	1881.	1893.
		Pounds.	*Pounds.*	*Pounds.*
2a	Farmyard manure since 1884	200	....	73.06
2b	Farmyard manure 50 years	200	57.84	85.99
3	Unmanured	0	41.90	38.33
4	Unmanured since 1852	0	33.78	41.35
5	Full minerals	0	63.50	50.88
6	Full minerals and ammonium salts	43	79.50	59.23
7	do	86	107.82	62.84
8	do	129	185.77	73.63
9a	Full minerals and sodium nitrate	43	78.51	40.64
9b	Sodium nitrate only	43	70.84	47.63
10a	Ammonium salts (no minerals since 1844)	86	131.91	73.65
10b	Ammonium salts (no minerals since 1850)	86	137.24	59.60
11	Phosphates and ammonium salts	86	93.01	58.64
12	Phosphates, sodium, and ammonium salts	86	130.99	65.27
13	Phosphates, potassium, and ammonium salts	86	95.97	81.12
14	Phosphates, magnesium, and ammonium salts	86	117.99	73.85
15	Full minerals and ammonium salts (autumn)	86	79.41	76.07
16	Full minerals and sodium nitrate since 1884	86	....	45.72
17	Full minerals and ammonium salts transposed in alternate years	86	61.86	48.74
18			120.98	71.44
19	Rape cake	93	38.36	66.34

It will be remembered that, of the ammonium salts used at Rothamsted, one-half of each application consists of ammonium chlorid; and that, on the plats so dressed, the quantity of chlorin found, in excess of that on the unmanured plats, was in 1893 very fairly proportional to the quantity added in the ammonium salts.

It will also be remembered that, when the 1893 chlorin results were discussed, the curious fact was pointed out that when the soils and subsoils were examined to as far down as ten successive depths of 9 inches each it was found that each plat contained a quantity of chlorin equivalent to that applied in one year's manurial dressing, plus the average chlorin of ten years' rainfall—an average year's rainfall at Rothamsted containing 14.75 pounds of chlorin per acre. Notwithstanding the constant percolation of rainfall, each 9 inches of subsoil is still found to contain, even when no chlorin is applied in manure, about 15 pounds of chlorin per acre, according to the results obtained in the analyses of the 1893 samples.

In comparing the 1881 and 1893 results, taking in the aggregate the three depths down to 27 inches, we find very little difference on the unmanured plats, 3 and 4. Plat 5 in 1881, as in 1893, was found to contain more chlorin than the unmanured plats, although not more than a few pounds per acre per annum are applied to it as impurities in the mineral fertilizers used.

On plats 6, 7, and 8 we find in 1881, as in 1893, a successive increase in chlorin as the quantity of ammonium salts grows successively larger; and the other results are for the most part fairly consistent. It is noticeable, however, throughout the ammonium-dressed plats, that notwithstanding the very much greater rainfall in the summer and autumn of 1881, the quantity of chlorids in these plats was found in October to be uniformly greater in 1881 than in 1893. As we have already seen, it is highly improbable that any tangible quantity of actual ammonium salts was left in the soil in the autumn of 1881, and the chlorin added in the form of ammonium salts must by that time have existed in mineral combination with calcium, magnesium, or other bases in the soil. The quantity of chlorin present in 1881 as compared with that found in 1893 was not only greater when the 27 inches were considered, but was even much greater in the surface soil than in the corresponding soils of 1893, as well as being, as a rule, much higher in the second and third depths. In fact, if we deduct the yield of the unmanured plats, we find that as a rule the quantity of what may be called manurial chlorin found in the first 27 inches of soil and subsoil in 1881 was two or three times as great as in 1893. It would seem that in 1881 chlorids which must have been initially washed farther down had, by a process of upward diffusion, readjusted themselves in the soil water under the influence of the evaporation produced by early autumnal heat.

PHOSPHORIC ACID (1865, 1881, AND 1893 RESULTS COMPARED).

The results of the phosphoric acid determinations made in the 1893 samples have been already discussed (see p. 98). It now only remains to examine, for the purpose of comparison, the results obtained in the analyses of the two earlier sets of samples. The complete results are shown in the following table:

TABLE 72.—*Broadbalk wheat soils—Samples collected in 1865, 1881, and 1893—* PHOSPHORIC-ACID *determinations.*

	Dissolved by strong hydrochloric or nitric acid.						Dissolved by 1 per cent solution of citric acid.					
	1865.		1881.		1893.		1865.		1881.		1893.	
	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
FIRST 9 INCHES OF SOIL.												
Plat 3	0.140	3,630	0.131	3,396	0.114	2,956	0.0094	244	0.0074	192	0.0078	202
Plat 4	......	......	......	......	.120	3,111	......	......	......	......	.0100	259
Plat 10a	.146	3,785	.126	3,267	.123	3,189	.0106	275	.0068	176	.0074	192
Plat 10b	......	......	.130	3,370	.126	3,267	......	......	.0092	239	.0074	192
Plat 7	......	......	......	......	.195	5,056	......	......	......	......	.0547	1,418
Plat 13	.174	4,511	.199	5,159	.205	5,315	.0261	677	.0383	993	.0434	1,125
Plat 14	.178	4,615	.189	4,900	.204	5,289	.0257	666	.0364	944	.0442	1,146
Plat 12	.183	4,744	.200	5,185	.201	5,211	.0268	695	.0386	1,001	.0413	1,071
Plat 11	.177	4,589	.184	4,770	.197	5,107	.0259	672	.0329	853	.0405	1,050
Plat 5	......	......	......	......	.219	5,678	......	......	......	......	.0642	1,665
Plat 2a	......	......	......	......	.165	4,142	......	......	......	......	.0321	806
Plat 2b	.189	4,685	.194	4,648	.215	5,018	.0355	880	.0372	891	.0560	1,307
SECOND 9 INCHES OF SOIL.												
Plat 3	0.116	3,009	0.093	2,484	0.113	3,019	0.0029	78	0.0020	53	0.0041	110
Plat 4	......	......	......	......	.106	2,832	......	......	......	......	.0024	64
Plat 10a	.128	3,419	.101	2,698	.111	2,965	.0031	83	.0018	48	.0031	83
Plat 10b	......	......	.113	3,019	.123	3,286	......	......	.0028	75	.0043	115
Plat 7	......	......	......	......	.086	2,297	......	......	......	......	.0038	102
Plat 13	.111	2,965	.108	2,885	.105	2,805	.0022	59	.0019	51	.0027	72
Plat 14	.118	3,152	.105	2,805	.111	2,965	.0024	64	.0016	43	.0023	61
Plat 12	.112	2,992	.112	2,992	.098	2,618	.0019	51	.0020	53	.0035	94
Plat 11	.106	2,832	.107	2,858	.108	2,885	.0022	59	.0017	45	.0028	75
Plat 5	......	......	......	......	.107	2,858	......	......	......	......	.0052	139
Plat 2a	......	......	......	......	.095	2,538	......	......	......	......	.0052	139
Plat 2b	.126	3,366	.111	2,965	.111	2,965	.0044	118	.0031	83	.0094	251
THIRD 9 INCHES OF SOIL.												
Plat 3	0.092	2,568	0.090	2,512	0.097	2,708	0.0012	34	0.0012	34	0.0021	59
Plat 4	......	......	......	......	.097	2,708	......	......	......	......	.0017	48
Plat 10a	.111	3,099	.090	2,512	.105	2,931	.0014	39	.0013	36	.0018	50
Plat 10b	......	......	.104	2,903	.111	3,099	......	......	.0012	34	.0021	59
Plat 7	......	......	......	......	.074	2,066	......	......	......	......	.0030	84
Plat 13	.093	2,596	.087	2,429	.081	2,261	.0012	34	.0010	28	.0016	45
Plat 14	.121	3,378	.104	2,903	.113	3,154	.0017	48	.0011	31	.0023	64
Plat 12	.103	2,875	.087	2,429	.082	2,289	.0014	39	.0012	34	.0020	56
Plat 11	.098	2,736	.096	2,680	.091	2,540	.0017	48	.0012	34	.0017	48
Plat 5	......	......	......	......	.112	3,126	......	......	......	......	.0036	101
Plat 2a	......	......	......	......	.084	2,345	......	......	......	......	.0028	78
Plat 2b	.103	2,875	.082	2,289	.083	2,317	.0015	42	.0017	48	.0034	95

Seeing that these results are fully discussed in the recent paper presented to the Royal Society, referred to on p. 111, we may here confine ourselves to a brief examination of the principal facts brought out by the comparative figures.

As far as the total phosphoric acid is concerned, it is sufficient to compare the first 9 inches of soil, the irregularities in the second and third depths being such as in many cases to overwhelm altogether such differences as would be due to the effects of manuring and cropping. In the case of the citric-acid results, the second and third depths in some instances afford an interesting subject for comparison.

Beginning with plat 3, which, it will be remembered, is continuously unmanured, we see from period to period, as indicated by the analyses of the 1865, 1881, and 1893 samples, a steady decrease in the total phosphoric acid. The same thing is seen in plat 10a, which receives only ammonium salts without minerals.

Plats 11, 12, 13, and 14 all show the progressive increase in total phosphoric acid due to the accumulation of residues of unused phosphatic manure, and the dunged plat, 2b, also shows a steady increase in total phosphoric acid from period to period.

When we regard the citric-acid-soluble phosphoric acid, we must bear in mind that the samples of 1865 and 1881 were not examined immediately after collection, but only in 1893, when they were, respectively, twenty-eight and twelve years old; and it is not certain whether the citric-acid-soluble phosphoric acid may not have undergone some modification during that time notwithstanding the fact that the samples were stored in an approximately dry state. Nevertheless they afford features of considerable interest and on the whole agree excellently with the history of the various plats represented.

In the case of the unmanured plat the citric-acid-soluble phosphoric acid decreased appreciably between 1865 and 1881, but does not appear to have decreased since. The same thing is to be noticed in the case of plat 10a, which receives only ammonium salts. In fact, in both these instances there appears, if anything, to be a slight increase between 1881 and 1893, and it would appear as though the quantity of citric-acid-soluble phosphoric acid in the surface soils of these plats had become reduced to a sort of natural level, at which the decomposition of crop residue and other influences producing readily available phosphoric acid from the natural resources of the soil approximately balance the annual quantity removed in crops.

In the case of plats 10a and 10b, the effect of the early mineral dressings on plat 10b seems to be clearly apparent in the 1881 samples.

The gradual accumulation of manurial phosphoric acid during the three periods on plats 11–14 is very strikingly seen in the citric-acid figures for these various plats, and this is also the case with the dunged plat, 2b.

When we come to the upper subsoil or second 9 inches we find in the unmanured plat (3) and the ammonium-salts plat (10a) a diminution in citric-acid-soluble phosphoric acid between 1865 and 1881, and then what appears to be a distinct reenforcement between 1881 and 1893, suggesting that possibly as the surface soil has grown more exhausted the roots of the wheat have taken to deeper growth to seek mineral food, and have thus left more root residue in the subsoil in the later years, the decay of which would show an increased quantity of phosphoric acid in an easily soluble form.

The same thing is to be noticed in the third 9 inches.

In connection with the 1893 results, the solvent action of alkaline salts on the phosphates of the subsoil was pointed out. This was most strikingly brought out on plats 5 and 7. Unfortunately, we have no analyses representing these plats in the earlier years, but we have the series of plats, 11, 12, 13, and 14, all receiving ammonium salts and phosphates, plat 11 without any alkaline salts, and plats 12, 13, and 14 with sodium, potassium, and magnesium salts, respectively. In most cases we find that in the second and third depths there is not very much difference between the samples of 1865 and those of 1881, but there appears to be distinct evidence of accumulation in both the second and third depths between 1881 and 1893, owing to descent of mineral phosphates.

To show how the results for the three periods compare quantitatively with the estimated additions and removals to and from the soil, I may here give a table taken from the Royal Society paper on the subject, showing how the excess or deficiency both of total and of citric-acid-soluble phosphoric acid, as against the unmanured plat (plat 3), compares with the expected excess per acre on each plat calculated from the known additions and removals of phosphoric acid to and from the soil. These data are given for the three periods of twenty-two years, thirty-eight years, and fifty years, respectively.

TABLE 73.—*Broadbalk wheat soils—Samples collected in 1865, 1881, and 1893.*

[Plats 7, 13, 14, 12, 11, and 5.]

	Estimated excess of phosphoric acid over plat 3, calculated from known additions and removals.	Excess of total phosphoric acid over plat 3, found by analysis in first 9 inches of soil.	Excess (+) or deficiency (−) of phosphoric acid soluble in 1 per cent citric-acid solution, as compared with plat 3.			
			First 9 inches.	Second 9 inches.	Third 9 inches.	Whole 27 inches.
	Lbs. per acre.	*Lbs. per acre.*	*Lbs. per acre.*	*Lbs. per acre.*	*Lbs. per acre.*	*Lbs. per acre.*
After 22 years (1844–1865):						
Plat 13	1,161	881	+ 433	−19	0	+ 414
Plat 14	1,198	985	+ 423	−13	+14	+ 424
Plat 12	1,161	1,114	+ 451	−27	+ 6	+ 430
Plat 11	1,175	959	+ 428	−19	+14	+ 423
After 38 years (1844–1881):						
Plat 13	1,985	1,763	+ 801	− 3	− 6	+ 792
Plat 14	2,045	1,504	+ 752	−11	− 3	+ 738
Plat 12	2,019	1,789	+ 809	0	0	+ 809
Plat 11	2,081	1,374	+ 661	− 8	0	+ 653
After 50 years (1844–1893):						
Plat 7	2,452	2,100	+1,216	− 8	+25	+1,233
Plat 13	2,587	2,359	+ 923	−37	−14	+ 872
Plat 14	2,667	2,333	+ 944	−48	+ 6	+ 902
Plat 12	2,651	2,255	+ 869	−16	− 3	+ 850
Plat 11	2,759	2,151	+ 848	−35	−11	+ 802
Plat 5	3,049	2,722	+1,462	+29	+42	+1,533

The descent in the continuously dunged plat, 2b, is strongly brought out in both the second and third depths when either the 1865 or the

1881 results are compared with those of 1893, though in the second depth the difference between the figures for 1865 and 1881 is not in the direction that would be expected.

POTASH (1865, 1881, AND 1893 RESULTS COMPARED).

We may now in the same way briefly examine the potash results for the samples of the three periods. These are recorded in the following table:

TABLE 74.—*Soils from Broadbalk wheat field, Rothamsted—Samples collected in 1865, 1881, and 1893*—POTASH *determinations.*

FIRST 9 INCHES OF SOIL.

	Dissolved by strong hydrochloric acid.						Dissolved by 1 per cent solution of citric acid.					
	1865.		1881.		1893.		1865.		1881.		1893.	
	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.
Plat 3	0.191	4,952	0.226	5,859	0.220	5,704	0.0040	104	0.0032	83	0.0032	83
Plat 4	------	------	------	------	.219	5,678	------	------	------	------	.0052	135
Plat 10a	.226	5,859	.224	5,807	.240	6,222	.0040	104	.0020	52	.0032	83
Plat 10b	------	------	.244	6,326	.234	6,067	------	------	.0032	83	.0040	104
Plat 11	.228	5,911	.243	6,300	.197	5,107	.0036	93	.0020	52	.0032	83
Plat 12	.232	6,015	.234	6,067	.223	5,782	.0060	156	.0060	156	.0040	104
Plat 14	.244	6,326	.251	6,507	.240	6,222	.0036	93	.0044	114	.0024	62
Plat 13	.269	6,974	.290	7,519	.273	7,078	.0200	519	.0228	591	.0188	487
Plat 7	------	------	------	------	.262	6,793	------	------	------	------	.0232	602
Plat 5	------	------	------	------	.279	7,233	------	------	------	------	.0308	799
Plat 2b	.273	6,767	.259	6,206	.285	6,652	.0300	744	.0284	681	.0384	896
Plat 2a	------	------	------	------	.277	6,953	------	------	------	------	.0330	828

SECOND 9 INCHES OF SOIL.

Plat 3	0.336	8,976	0.407	10,872	0.335	8,949	0.0028	75	0.0044	118	0.0060	160
Plat 4	------	------	------	------	.414	11.059	------	------	------	------	.0060	160
Plat 10a	.360	9,617	.336	8,976	.394	10,525	.0048	128	.0024	64	.0032	86
Plat 10b	------	------	.374	9,991	.359	9,590	------	------	.0028	75	.0052	139
Plat 11	.472	12,609	.409	10,926	.357	9,537	.0052	139	.0024	64	.0028	75
Plat 12	.384	10,258	.390	10,418	.371	9,911	.0040	107	.0028	75	.0040	107
Plat 14	.491	13,116	.403	10,765	.404	10,792	.0052	139	.0040	107	.0048	128
Plat 13	.382	10,204	.446	11,914	.379	10,124	.0120	321	.0128	342	.0136	363
Plat 7	------	------	------	------	.361	9,643	------	------	------	------	.0140	374
Plat 5	------	------	------	------	.410	10,952	------	------	------	------	.0224	598
Plat 2b	.334	8,922	.366	9,777	.318	8,495	.0140	374	.0176	470	.0276	737
Plat 2a	------	------	------	------	.398	10,632	------	------	------	------	.0168	449

THIRD 9 INCHES OF SOIL.

Plat 3	0.459	12,813	0.466	13,008	0.495	13,818	0.0032	89	0.0040	112	0.0072	201
Plat 4	------	------	------	------	.507	14,153	------	------	------	------	.0044	123
Plat 10a	.511	14,265	.475	13,260	.533	14,879	.0044	123	.0028	78	.0048	134
Plat 10b	------	------	.469	13,092	.507	14,153	------	------	.0028	78	.0036	101
Plat 11	.489	13,650	.452	12,618	.459	12,813	.0036	101	.0028	78	.0036	101
Plat 12	.456	12,729	.505	14,097	.488	13,623	.0048	134	.0028	78	.0036	101
Plat 14	.540	15,074	.546	15,242	.408	11,389	.0040	112	.0056	156	.0052	145
Plat 13	.458	12.785	.493	13,762	.433	12,087	.0044	123	.0032	89	.0084	235
Plat 7	------	------	------	------	.459	12,813	------	------	------	------	.0064	179
Plat 5	------	------	------	------	.472	13,176	------	------	------	------	.0092	257
Plat 2b	.410	11,445	.532	14,851	.415	11,585	.0040	112	.0052	145	.0128	357
Plat 2a	------	------	------	------	.499	13,930	------	------	------	------	.0096	268

With regard to the hydrochloric-acid-soluble potash little need be added to what has already been said in discussing the 1893 results. Such a method of analysis does not serve to give consistent comparative results. I therefore now direct attention simply to the citric-acid figures.

In the case of the unmanured plat it would appear that in 1865, after over twenty years of unmanured cropping, the available potash had already been reduced to a low ebb, and that in the surface soil it has since fallen still lower, though in the second and third depths it would seem to have increased.

This decrease to a practically stationary point in the surface soil, accompanied by an increase in the lower depths, was also noticed in the case of the phosphoric acid, but the increase, especially in the third depth, is more marked in the case of the potash. It has already been suggested that this may to some extent be attributable to the deeper extension of root growth as the surface soil has become poorer and to the accumulation of root remains thus formed.

In the case of plats 10a and 10b, receiving ammonium salts only, we find that the very early dressings of minerals (which included 300 pounds of potash per acre), applied in 1848 and 1850 to plat 10b, seemed to show in 1881, as in 1893, an appreciable effect on the citric-acid-soluble potash, both in the first and second depths. Plat 10a seems to have reached in 1893 the same level of available potash as the unmanured plat after a diminution between 1865 and 1881. As a matter of fact, in 1865 plat 10a was showing little indication of potash exhaustion, for in 1866 its crop yielded 29 pounds of potash per acre, while that of plat 3 contained but 16 pounds of potash per acre. It is possible that the ammonium salts acted as solvents on the soil potash. By 1881, however, plat 10a seems to have become appreciably poorer in potash than plat 3 in all three depths. But by 1893 there is a recovery throughout in plat 10a, possibly owing to the greatly diminished output of crop on account of the failure of phosphatic food and to the continued solvent action of the ammonium salts, and possibly (for the increase is mainly in the subsoil) partly owing to the effects of deeper root development.

On plats 11, 12, and 14, which receive ammonium salts and phosphates without potash, there is in the surface soils a uniform diminution between 1865 and 1893, and in two of the three cases between 1881 and 1893. If we compare the 1865 and 1893 figures for the second depths of the same plats we also see, on the whole, a diminution.

When the results for the potash-manured plat (13) are examined the effect of the potash salts is strikingly seen in all three sets of samples not only in the first depth of the soil but also in the second 9 inches. In the third 9 inches the difference is clearly apparent only in the 1893 samples.

The comparative significance of the results obtained in the samples drawn at the end of each of the three periods may be studied in the following table, which I also quote from the paper presented to the Royal Society.

As in the corresponding phosphoric-acid table, the estimated excess or deficiency of potash on each plat is obtained by taking into account the known additions of manurial potash to the soil and the quantity of potash, as ascertained by analysis, in the crops removed from each plat.

TABLE 75.—*Broadbalk wheat soils—Samples collected in 1865, 1881, and 1893.*

[Plats 11, 12, 13, 14, 7, and 5. POTASH per acre dissolved by 1 per cent citric-acid solution.]

Plat.	Treatment since 1851.	Found.				More (+) or less (−) than plat 11.				Estimated excess (+) or deficiency (−) compared with plat 11.
		First 9 inches.	Second 9 inches.	Third 9 inches.	27 inches.	First 9 inches.	Second 9 inches.	Third 9 inches.	27 inches.	
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Pounds.*
	AFTER TWENTY-TWO YEARS (1844-1865).									
11	Nitrogen and phosphates	93	139	101	333	......	......	......	......	......
12	Nitrogen and phosphates and sodium salts (some potash in earlier years)	156	107	134	397	+ 63	− 32	+ 33	+ 64	+ 309
14	Nitrogen and phosphates and magnesium salts (some potash in earlier years)	93	139	112	344	0	0	+ 11	+ 10	+ 219
13	Nitrogen and phosphates and potassium salts	519	321	123	963	+426	+182	+ 22	+ 630	+2,021
	AFTER THIRTY-EIGHT YEARS (1844-1881).									
11	Nitrogen and phosphates	52	64	78	194	......	......	......	......	......
12	Nitrogen and phosphates and sodium salts (some potash in earlier years)	156	75	78	309	+104	+ 11	0	+ 115	+ 159
14	Nitrogen and phosphates and magnesium salts (some potash in earlier years)	114	107	156	377	+ 62	+ 43	+ 78	+ 183	+ 54
13	Nitrogen and phosphates and potassium salts	591	342	89	1,022	+539	+278	+ 11	+ 828	+3,222
	AFTER FIFTY YEARS (1844-1893).									
11	Nitrogen and phosphates	83	75	101	259	......	......	......	......	......
12	Nitrogen and phosphates and sodium salts (some potash in earlier years)	104	107	101	312	+ 21	+ 32	0	+ 53	+ 20
14	Nitrogen and phosphates and magnesium salts (some potash in earlier years)	62	128	145	335	− 21	+ 53	+ 44	+ 76	− 92
13	Nitrogen and phosphates and potassium salts	487	363	235	1,087	+404	+288	+134	+ 826	+4,052
7	Nitrogen phosphates, potassium, sodium, and magnesium salts	602	374	179	1,155	+519	+299	+ 78	+ 896	+3,662
5	Potassium, sodium, and magnesium salts, but no nitrogen	799	598	257	1,654	+716	+523	+156	+1,395	+5,242

In the case of the continuously dunged plat 2b, the accumulation of potash from period to period is not at all indicated by the hydrochloric-acid results, but is qualitatively brought out very clearly in a comparison either of the 1865 and 1893 citric-acid results or of those of 1881 and 1893, particularly if the second and third depths be taken into account, though the increase between 1865 and 1881 is not what would have been expected. Nevertheless the gradual accumulation of potash in the two successive depths of subsoil by downward percolation is clearly seen in the analyses of the samples representing these two depths in the various years.

Section IV.

THE HOOS FIELD BARLEY SOILS.

BRIEF HISTORY.

The Hoos field experiments on the continuous growth of barley were very fully discussed in Sir Henry Gilbert's lectures in relation both to the yield of crops under the various manurial conditions observed and to the composition of the crops.

Fewer and less complete examinations have been made of the soils of the barley field than of those of the wheat field, but it is desirable that the results should be chronicled and briefly discussed, if only for comparison with those of the wheat soils.

The scheme of manuring and the crop results up to the time of the last analyses of the soils for nitrogen contents (1882) may first be recalled to you by the following table, condensed from the Rothamsted Memoranda:

Table 76.—*Hoos field continuous barley plats.*

Series.	Plat.	Treatment.	Average annual produce per acre (thirty years, 1852-1881.)	
			Grain.	Straw.
			Bushels.	*Cwt.*
O, No nitrogen	1	No phosphates or potash, etc.	17 7/8	10 1/8
	2	3½ hundredweight superphosphate	23	11 5/8
	3	200 pounds potassium sulphate, 100 pounds sodium sulphate, 100 pounds magnesium sulphate (no phosphates).	19 1/8	10 3/8
	4	3½ hundredweight superphosphate, together with potassium, sodium, and magnesium salts, as on plat 3.	24 1/4	12 3/8
A, 200 pounds ammonium salts, containing 43 pounds nitrogen.	1	No phosphates or potash, etc.	30 3/4	16 7/8
	2	Superphosphate as on plat 2	44 7/8	25 1/4
	3	Potassium, sodium, and magnesium salts, as on plat 3.	33 1/2	19
	4	Superphosphate and potassium, sodium, and magnesium salts, as on plat 4.	44 1/2	26 3/4
AA, 275 pounds sodium nitrate, containing 43 pounds nitrogen.	1	No phosphates or potash, etc.	34 1/8	19 7/8
	2	Superphosphate	46 7/8	28
	3	Potassium, sodium, and magnesium salts	34 7/8	21 3/4
	4	Superphosphate and potassium, sodium, and magnesium salts.	47 1/8	29 3/4
AAS, 275 pounds sodium nitrate and 400 pounds sodium silicate.	1	No phosphates or potash, etc.	36	20 3/4
	2	Superphosphate	45 3/4	26 7/8
	3	Potassium, sodium, and magnesium salts	40 3/8	22 7/8
	4	Superphosphate and potassium, sodium, and magnesium salts.	47 3/4	29 5/8
C, 1,000 pounds rape cake.	1	No phosphates or potash, etc., except contained in the rape cake.	43 1/4	24 7/8
	2	Superphosphate	45	26 3/8
	3	Potassium, sodium, and magnesium salts	52 7/8	25
	4	Superphosphate and potassium, sodium, and magnesium salts.	52 3/4	27 3/8
7	1	Farmyard manure for twenty years, but unmanured since 1871.	43 5/8	25
7	2	Farmyard manure continuously	49	28 7/8

Samples were drawn for analysis in March, 1868, and in March, 1882, to three successive depths of 9 inches, or 27 inches in all.

TOTAL NITROGEN.

The following table (Table 77) shows the total nitrogen found in all the samples that were examined in 1868, and in all of the soils and most of the subsoils sampled in 1882. The results are shown both as percentages and as pounds per acre, and it should here be stated that the weights of soil per acre taken for all computations of acreage weights in the Hoos field barley plats were as follows:

TABLE 77.—*Hoos field continuous barley plats—Adopted weights of fine dry soil per acre.*

	First 9 inches.	Second 9 inches.	Third 9 inches.
	Pounds	*Pounds.*	*Pounds.*
Used for series O, A, AA, and AAS	2,527,879	2,593,853	2,661,134
Used for series C	2,361,461		
Used for plat 7 (1)	2,486,870		
Used for plat 7 (2)	2,084,567		

Notice should be taken of the fact that the nitrogen results are all those of determinations by the soda-lime method and not by the modern Kjeldahl method. (See discussion of the results of the two processes in connection with the wheat-soil results).

TABLE 78.—*Hoos field continuous barley plats—Total* NITROGEN (*by soda-lime method*), *stated as percentages of fine dry soil and as pounds per acre, in samples collected March, 1868, and February–March, 1882.*

Series.	Plat.	First 9 inches.				Second 9 inches.				Third 9 inches.			
		Collected March, 1868.		Collected February–March, 1882.		Collected March, 1868.		Collected February–March, 1882.		Collected March, 1868.		Collected February–March, 1882.	
		Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Pounds per acre.	Per cent.	Lbs. per acre.
O	1	......	......	0.0930	2,351	......	......	0.0652	1,691	......	......	0.0490	1,304
	2	......	......	.0897	2,268	......	......	.0538	1,395	......	......	.0409	1,088
	3	......	......	.0970	2,452	......	......	......	......	......	......	......	......
	4	0.1202	3,039	.1124	2,841	0.0752	1,951	.0837	2,171	0.0708	1,884	.0730	1,943
A	1	......	......	.0900	2,275	......	......	.0660	1,712	......	......	.0553	1,472
	2	......	......	.1020	2,578	......	......	.0649	1,683	......	......	.0647	1,722
	3	......	......	.1040	2,629	......	......	......	......	......	......	......	......
	4	.1124	2,841	.1096	2,771	.0802	2,080	.0772	2,002	.0763	2,030	.0620	1,650
AA	1	......	......	.1080	2,730	......	......	......	......	......	......	......	......
	2	......	......	.1078	2,725	......	......	.0759	1,969	......	......	.0639	1,700
	3	......	......	.1112	2,811	......	......	......	......	......	......	......	......
	4	.1214	3,069	.1057	2,672	.0760	1,971	.0683	1,772	.0628	1,671	.0536	1,426
AAS	1	......	......	.1042	2,634	......	......	.0793	2,057	......	......	......	......
	2	......	......	.1135	2,869	......	......	.0636	1,650	......	......	.0646	1,719
	3	......	......	.1133	2,864	......	......	......	......	......	......	......	......
	4	......	......	.1023	2,586	......	......	.0685	1,777	......	......	......	......
C	1	......	......	.1234	2,914	......	......	.0633	1,642	......	......	.0537	1,429
	2	......	......	.1207	2,850	......	......	.0684	1,774	......	......	.0632	1,682
	3	......	......	.1330	3,141	......	......	.0613	1,590	......	......	.0543	1,445
	4	.1366	3,226	.1306	3,084	.0739	1,917	.0733	1,901	.0523	1,392	.0631	1,679
7	1	......	......	.1798	4,471	......	......	.0811	2,104	......	......	.0605	1,610
	2	......	......	.2131	4,442	......	......	.0836	2,168	......	......	.0523	1,392

The plats composing the series O1 to O4 have been continuously deprived of nitrogenous manure. Plat O1 has received no mineral manure either, and is comparable with plat 3 in the wheat field. Plats O2 and O3 have received, respectively, phosphates without alkalies and alkalies (potassium, sodium, and magnesium salts) without phosphates. They have no exact counterpart in the case of the wheat soils. Plat O4 receives both phosphates and alkalies, and corresponds with plat 5 of the wheat field—manured with "full minerals" without nitrogen.

The completely unmanured plat shows 0.0930 per cent of nitrogen, as against 0.1009 per cent on the unmanured wheat plat (No. 3) at about the same date (1881), and is therefore rather poorer. Plat O4 shows much more than the similar wheat plat (No. 5), namely, 0.1124 per cent, as against 0.0981.

This latter result is at first sight very puzzling. We should have expected the soil of plat O4 to be poorer than that of either of the plats 1, 2, or 3 of its own section, as was the case with the corresponding plats on the wheat field; or even if the accumulation of roots and stubble from its larger crops had caused any slight rescue of nitrogen, the difference from such a cause would hardly be very appreciable under the circumstances. But we see that it is actually richer than its neighbors by nearly 400 pounds of nitrogen per acre. We also may notice that, in the second depth, this plat also seems to be the richest of all the plats of all the sections, except the continuously dunged plat; and in the third depth it is richer even than the dunged plat. It may be seen that this curious plat (O4) was also very rich in nitrogen in 1868; and in 1882—anticipating other results to be subsequently discussed—it may be also observed that it accorded with the general rule, viz, that the more the total nitrogen (in a drained soil) the greater the quantity of nitrates, for we find, even in February or March, after the winter rains, that this plat is distinctly richer in nitric nitrogen than either 1, 2, or 3 of the same series. Sir Henry Gilbert has furnished me with a key to the mystery of this apparently anomalous and unexpected richness in nitrogen, and I think you will agree with me that the explanation is one of remarkable interest.

You are well aware how profoundly continuous manurial treatment in one direction or another alters the botanical composition of the herbage on grass land. This is exemplified in a most striking degree in the Rothamsted grass plats. There we find that an abundant supply of phosphates and potash salts tends to increase the non-gramineous, and more especially leguminous, vegetation—notably clover and trefoils—while on this soil nitrogenous manuring without minerals tends to their extermination, because the true grasses can live longer and better under such conditions than the clovers, etc., and so crowd them out; and the more the mixture of manures tends toward the extreme of purely mineral fertilizers in the one direction or of purely nitrogenous fertilizers in the other, the more is the herbage modified in one direction or another, the proportion of true gramineous growth falling or rising. The character of both gramineous and nongramineous herbage—that is to say, the prevalence or scarcity, or even disappearance, of various species of either the gramineous or the miscellaneous nongramineous herbage—is further influenced and modified, according to the nature of the nitrogenous manure used or the constituents of the "mineral" fertilizers apart from and in presence of each other. The use of full dressings of phosphates and alkaline salts—including especially potassium salts—without nitrogen is, on the grass land, found to be particularly favorable to the increase and domination of the Leguminosæ, presumably because these are, in virtue of the symbiotic functions of the microorganisms in their root nodules, able to gather and accumulate free nitrogen.

It is not singular that what applies to the pasture of a grass park should also apply to the natural wild vegetation to which, speaking as farmers or gardeners, we apply the generic name of "weeds." Now even the careful weeding that is carried out on the Rothamsted experimental cereal plats has no magic power to prevent the growth of weeds during the actual growth of a grain crop after it is tall enough to prohibit the use of the hoe; and Hoos field, like other grain fields, grows its inevitable share of weeds. It happens that the selective action of manures on weeds is especially marked on plat 4 of section O. The most prevalent weeds on the other sections are *Atriplex angustifolia* (narrow-leaved orache) and *Convolvulus arvensis* (small bindweed). On section O, and very especially on plat 4 of this section, however, the prevalent weed is *Medicago lupulina* (yellow trefoil or "black medick"), a leguminous plant which, in presence of the full dressing of superphosphate with potassium, sodium, and magnesium salts, is in some seasons very luxuriant. Thus in 1889 it was noticed that half of the weight of the "offal" from the barley crop on this plat consisted of the mere seed of this plant. During the past season—1900—the soil of plat O4 was literally covered with this weed, while on plats 4A, 4AA, and 4AAS, with the same mineral manure, but with liberal nitrogen supply also, there were only a few individual plants of this or any other member of the same natural order, the weeds being mainly the two species of nonleguminous vegetation just referred to.

It was also noticed that in this season, which was particularly favorable to the growth of the *Medicago lupulina*, plat O1, quite unmanured, had only about one-tenth of the quantity of this plant found on plat O4, while plat O2, manured with superphosphate only, had about one-eighth, and plat O3 (potassium, sodium, and magnesium salts without phosphates), about one-fifth as much. This weed, then, occurs to some extent on all the plats receiving no nitrogenous manure, but especially on plat O4, manured with full minerals.

Knowing what we do of the habits of the Leguminosæ, we can not doubt that the growth of this weed year after year must add nitrogen to the soil, and Sir Henry Gilbert is of opinion—and in the light of recent knowledge it would be difficult to dissent from his view—that the high nitrogen of the soil of plat O4 is to be accounted for by the nitrogen storage produced by the constant growth and plowing in of this leguminous weed. The other plats on section O—especially plat 3—would also be to some extent enriched in the same way, but not to anything approaching the same extent as plat 4. Plat O4 had, up to 1881, produced on an average 1¼ bushels of grain and three-fourths hundredweight of straw more than plat O2, and 4⅜ bushels of grain and 1¾ hundredweight of straw more than plat O3; but it produced as much as 6⅜ bushels of grain and 2¼ hundredweight of straw per acre per annum more than plat O1.

We do not find the same conspicuous difference in produce between plats 3 and 5 on the wheat field as between plats O1 and O4, the corresponding plats of the barley field. In the former case, for the same thirty years, the fully minerally manured wheat plat without nitrogen only beat the wholly unmanured plat by an average of 2¼ bushels of grain and 1¾ hundredweight of straw, while on these barley plats, as we have just seen, the gain was 6⅜ bushels of grain and 2¼ hundredweight of straw.

Plat O4 contained in 1881, in the first 9 inches, 490 pounds, 573 pounds, and 389 pounds, respectively, more nitrogen per acre than plats 1, 2, and 3 of its own section, in addition to a large quantity in the subsoil. The conservation of nitrogen in increased crop residue would, it need scarcely be said, account for no such excess as we find in plat O4, which we must attribute to the leguminous influence aforesaid.

In the A section, in which ammonium salts are used throughout, the crop on plat 1 (ammonium salts alone) has been greater than on any of the O plats, and its proportion of nitrogen is even lower. The nitrogen is considerably higher, however, on plats 2, 3, and 4, which receive minerals also, being highest on the most fully manured and most abundantly yielding plat, No. 4. in the surface soil of which we find 0.1096 per cent of nitrogen.

The next two sections, AA and AAS, receive annually the same quantity of nitrogen as section A, but differ from it inasmuch as the nitrogen is supplied in the form of sodium nitrate instead of in the form of ammonium salts. Section AAS is also supplied with sodium silicate. Both of these nitrate sections have given on the average considerably larger crops than the ammonium-salts section. Even on plat 1, receiving no phosphates or potassium salts, etc., there has been a much more abundant yield, possibly owing to some extent to the solvent action of the sodium salt on the mineral constituents of the soil. In three out of the four plats of the nitrate sections we find more total nitrogen in the surface soil than in the corresponding plats of the ammonium-salts section. In the case of plat 4 of both AA and AAS (fully manured) the nitrogen is rather less than on plat A4, the soil having probably reached the stage in which nitrification had become more active than in the case of plat A4.

Plat AA4 seems to have been richer than the corresponding ammonium-salts plat in 1868, but its nitrogen has since diminished, as in the case of the other section.

The rape-cake plats (section C) are, as we should expect, all rich in nitrogen. Plats 3 and 4, which have given the best crops, are the richest. Much of the accumulation of nitrogen in this section must be attributed to actual accumulation of added nitrogenous matter and not to mere crop residue. Plat 4 gave lower results in 1882 than in 1868, a possible inference from which is that nitrification had become more active as the soil became richer.

The farmyard-manure plats show a much larger accumulation of total nitrogen, the quantity, as we should expect, being considerably greater in the case of the continuously dunged plat than in the case of the plat on which the application of dung was stopped eleven years before, though this latter plat is still far richer in nitrogen than even the rape-cake plats. On the dunged plats the richness in nitrogen seems to appear also in the second depth; but the subsoils, like those of the Broadbalk field, are irregular.

A table is here added showing the difference in nitrogen between the surface soils of the plats of the sections A, AA, AAS, and C, all nitrogenously manured, and those of the corresponding plats of section O, without nitrogenous manure. Plats 1, 2, 3, and 4 in every section receive, it will be remembered, the same minerals. The difference between plats 1, or 2, or 3, or 4 of section O, and the correspondingly treated plat of any other section, is, therefore, to be referred solely to the direct or indirect treatment of the latter with nitrogenous fertilizers.

TABLE 79.—*Hoos field barley soils, samples collected February-March, 1882—* NITROGEN *in first 9 inches of soil, stated as percentages of fine dry soil and as pounds per acre; also differences between plats of section O, and those of other sections.*

Section.	Plat.	Nitrogen.		Nitrogen per acre.	
		Per cent.	+ or − section O.	Actual.	+ or − section O.
				Pounds.	*Pounds.*
O (no nitrogen)	1	0.0930	----------	2,351	----------
	2	.0897	----------	2,268	----------
	3	.0970	----------	2,452	----------
	4	.1124	----------	2,841	----------
A (ammonium salts)	1	.0900	−0.0030	2,275	− 76
	2	.1020	+ .0123	2,578	+310
	3	.1040	+ .0070	2,629	+177
	4	.1096	− .0028	2,771	− 70
AA (sodium nitrate)	1	.1080	+ .0150	2,730	+379
	2	.1078	+ .0181	2,725	+457
	3	.1112	+ .0142	2,811	+359
	4	.1057	− .0067	2,672	−169
AAS (sodium nitrate and sodium silicate)	1	.1042	+ .0112	2,634	+283
	2	.1135	+ .0238	2,869	+601
	3	.1133	+ .0163	2,864	+412
	4	.1023	− .0101	2,586	−255
C (rape cake)	1	.1234	+ .0304	2,914	+563
	2	.1207	+ .0310	2,850	+582
	3	.1330	+ .0360	3,141	+689
	4	.1306	+ .0182	3,084	+243

It will be seen that in every section plat 4 (with full minerals and nitrogen) seems to contradict all the teaching of the other plats by its lowness in comparison with plat O4, also receiving full minerals, but without nitrogen. This apparent anomaly is due to the leguminous weed vegetation on the last-named plat, already fully discussed. Excluding plats 4, we find, as in the case of the wheat soils, that the accumulations of crop residue under manuring and higher cropping have produced or maintained in the surface soil of the various sections a greater quantity of nitrogen than we find on section O, without nitrogenous manures, except in one case, viz, that of the continuous application of ammonium salts without minerals. This has left the soil slightly poorer in nitrogen, if anything, than has the absolute unmanuring on plat O1, showing once more that even if largely unutilized through lack of phosphates and other mineral constituents, ammonium salts do not accumulate, even in clay soil, in such a degree as to appreciably affect the permanent proportion of total fixed nitrogen.

On the corresponding sodium nitrate plats, on the other hand, we find an accumulation or increase of nitrogen; but this again is not accumulation of manure but of crop residue, due to the persistently larger yield of both grain and straw under the influence of the nitrate when minerals are not applied.

CARBON, AND RATIO OF CARBON TO NITROGEN.

The carbon was not determined in the earlier samples, but only in those collected in 1882. The following table shows the percentages of carbon side by side with the percentages of total nitrogen, and the ratios of carbon to 1 nitrogen, and of nitrogen to 100 carbon:

TABLE 80.—*Hoos field barley soils, samples collected February-March, 1882*—NITROGEN *and* CARBON *in first, second, and third depths of 9 inches each, stated as percentages of fine, dry soil; also ratios of carbon to 1 nitrogen, and nitrogen to 100 carbon.*

Section.	Plat.	First 9 inches.				Second 9 inches.				Third 9 inches.			
		Nitrogen.	Carbon.	Carbon to 1 nitrogen.	Nitrogen to 100 carbon.	Nitrogen.	Carbon.	Carbon to 1 nitrogen.	Nitrogen to 100 carbon.	Nitrogen.	Carbon.	Carbon to 1 nitrogen.	Nitrogen to 100 carbon.
		Per cent.	*Per cent.*			*Per cent.*	*Per cent.*			*Per cent.*	*Per cent.*		
O	1	0.0930	1.021	11.0	9.11	0.0652	......	......	......	0.0490	......	......	......
	2	.0897	.957	10.7	9.37	.0538	0.488	9.1	11.02	.0409	0.414	10.1	9.88
	3	.0970	1.007	10.4	9.63	......	......	......	......	......	......	......	......
	4	.1124	1.154	10.3	9.74	.0837	......	......	......	.0730	......	......	......
A	1	.0900	1.026	11.4	8.77	.0660	......	......	......	.0553	......	......	......
	2	.1020	1.060	10.4	9.62	.0649	.555	8.6	11.69	.0647	.519	8.0	12.47
	3	.1040	1.007	9.7	10.33	......	......	......	......	......	......	......	......
	4	.1096	1.082	9.9	10.13	.0772	......	......	......	.0620	......	......	......
AA	1	.1080	1.110	10.3	9.73	......	......	......	......	......	......	......	......
	2	.1078	1.171	10.9	9.21	.0759	.683	9.0	11.11	.0639	.521	8.2	12.26
	3	.1112	1.117	10.0	9.96	......	......	......	......	......	......	......	......
	4	.1057	1.119	10.6	9.45	.0683	......	......	......	.0536	......	......	......
AAS	1	.1042	1.071	10.3	9.73	.0793	......	......	......	......	......	......	......
	2	.1135	1.198	10.6	9.47	.0636	......	......	......	.0646	......	......	......
	3	.1133	1.174	10.4	9.65	......	......	......	......	......	......	......	......
	4	.1023	1.098	10.7	9.32	.0685	......	......	......	......	......	......	......
C	1	.1234	1.327	10.8	9.30	.0633	......	......	......	.0537	......	......	......
	2	.1207	1.313	10.9	9.19	.0684	.642	9.4	10.65	.0632	.507	8.0	12.47
	3	.1330	1.375	10.3	9.67	.0613	......	......	......	.0543	......	......	......
	4	.1306	1.355	10.4	9.64	.0733	......	......	......	.0631	......	......	......
7	1	.1798	2.032	11.3	8.85	.0811	.638	7.9	12.71	.0605	.542	9.0	11.16
	2	.2131	2.486	11.7	8.57	.0836	.727	8.7	11.49	.0523	.506	9.7	10.34

The first point that we naturally look to in the carbon results is to see how far the quantity of carbon on plat 4 of section O (the plat which grows the large quantity of the yellow trefoil as a weed) accords with the high proportion of nitrogen contained in that plat. We see at once that there is a close correspondence.

The other plats do not differ much in carbon from those of section A (ammonium salts), but the plats of the two sodium nitrate sections give uniformly a higher percentage of carbon than the ammonium salts plats, showing generally pretty clearly the influence of greater crop residue accumulation following greater crops.

On the rape-cake plats the actual accumulation of added organic matter is distinctly indicated by a decidedly larger carbon accumulation; and, as we should expect, we notice the same thing, but to a much larger extent, in the case of the two farmyard-manure plats, the one on which dung was discontinued in 1871 showing (also as we should expect) a smaller accumulation of organic carbon than the plat dunged continuously.

On the whole, the proportions of nitrogen in the various plats of the barley field that have been persistently manured with chemical fertilizers resemble very closely the proportions found in the wheat plats more or less similarly manured, and the proportions of carbon are, on the whole, also very similar.

On the rape-cake plats of the barley field the proportion of total nitrogen varies from about 0.12 to about 0.13. On the rape-cake wheat plat the quantity at about the same time (1881) was 0.123 per cent, or about the same.

The quantity of carbon in the rape-cake barley plats is from about 1.31 to about 1.37 per cent. On the wheat plat, at about the same period, it was about 1.37 per cent.

On the continuously dunged barley plat the proportion of total nitrogen is 0.2131 per cent. On the wheat plat the proportion of total nitrogen at about the same period was 0.1836 per cent, or rather less.

The carbon in the case of the continuously dunged barley plat is 2.486 per cent. On the wheat plat it was 2.132 per cent.

The general ratio of carbon to nitrogen does not differ very much from that found in the wheat plats. Excluding the dunged plats, the ratio of carbon to nitrogen on the barley plats averages 10.5 of carbon to 1 of nitrogen. On the wheat plats, at about the same period, it averaged 10.6 to 1.

The continuously dunged plat on the barley field shows, in 1882, a ratio of 11.7 of carbon to 1 of nitrogen, while the continuously dunged plat on the wheat field, in 1881, showed a ratio of 11.7 of carbon to 1 of nitrogen.

In the second 9 inches of the barley soils the ratio of carbon to 1 of nitrogen varies from 8.7 to 9.4. In the second depth of the wheat soils, at about the same period, it averaged 9.1.

In the third 9 inches the ratio of carbon to 1 of nitrogen varies, in the barley soils, from 8 to 10.1. On the wheat soils it averaged 8.7.

On the whole, then, there is very little difference between either the proportions of carbon or the proportions of nitrogen in the various depths of the two fields, as far as we are able to compare them.

It should be mentioned that all these comparisons are based upon the percentages of nitrogen as determined in both sets of samples by the soda-lime method and not by the Kjeldahl process.

NITROGEN AS NITRATES ("NITRIC" NITROGEN).

The nitrogen existing as nitrates was determined by Professor Warington in all of the 1882 samples except those of the sodium-silicate section, AAS. In regarding these results it must be borne in mind that the samples were collected in February and March, nearly a year having elapsed, therefore, since the application of the annual dressings of manure on each plat. Most of the nitric nitrogen present in the surface soil, therefore, would be mainly nitric nitrogen of the year before, which had not been washed out by the winter drainage, or which, by upward diffusion under the influence of evaporation, had regained the surface, though there would, perhaps, be some small quantity formed by early spring nitrification. The winter had been more than ordinarily wet.

The nitric nitrogen for all the plats sampled in 1882 is given in the following table.

Professor Warington also determined the chlorin in the plats of two sections, and the results are given in the same table.

TABLE 81.—*Hoos field barley soils, samples collected February-March, 1882*—NITROGEN *as* NITRATES (*"nitric" nitrogen*), *and chlorin stated as parts per million of fine dry soil and as pounds per acre in first, second, and third depths of 9 inches each.*

NITRIC NITROGEN.

Series.	Plat.	Parts per million of fine dry soil.			Pounds per acre.			
		First 9 inches.	Second 9 inches.	Third 9 inches.	First 9 inches.	Second 9 inches.	Third 9 inches.	Total (27 inches).
O	1	2.34	1.81	1.90	5.92	4.69	5.06	15.67
	2	2.52	2.18	2.36	6.37	5.65	6.28	18.30
	3	2.41	2.19	2.43	6.09	5.68	6.47	18.24
	4	2.95	3.75	2.36	7.46	9.73	6.28	23.47
A	1	2.42	3.20	2.61	6.12	8.30	6.95	21.37
	2	2.93	4.43	3.07	7.41	11.49	8.17	27.07
	3	2.97	2.38	2.11	7.51	6.17	5.61	19.29
	4	3.20	2.22	3.34	8.09	5.76	8.89	22.74
AA	1	3.84	2.63	3.38	9.71	6.82	8.99	25.52
	2	3.09	4.02	3.10	7.81	10.43	8.25	26.49
	2	3.07	2.39	3.04	7.76	6.20	8.09	22.05
	4	3.72	2.19	2.34	9.40	5.68	6.23	21.31
C	1	4.50	5.28	2.98	10.63	13.70	7.93	32.26
	2	3.16	5.03	2.94	7.46	13.05	7.82	28.33
	3	4.48	4.31	3.56	10.58	11.18	9.47	31.23
	4	3.48	4.44	3.27	8.22	11.52	8.70	28.44
7	1	5.96	4.54	4.09	14.82	11.78	10.88	37.48
	2	8.92	5.62	4.10	18.59	14.58	10.91	44.08

CHLORIN.

Series.	Plat.	First 9 inches.	Second 9 inches.	Third 9 inches.	First 9 inches.	Second 9 inches.	Third 9 inches.	Total (27 inches).
O	1	3.31	6.98	6.77	8.37	18.11	18.02	44.50
	2	3.30	7.17	12.73	8.34	18.60	33.88	60.82
	3	3.27	7.40	7.00	8.27	19.19	18.63	46.09
	4	2.81	10.65	14.37	7.10	27.62	38.24	72.96
A	1	3.14	7.64	9.56	7.94	19.82	25.44	53.20
	2	3.86	15.28	13.59	9.76	39.63	36.16	85.55
	3	5.29	6.56	6.88	13.37	17.02	18.31	48.70
	4	3.68	6.89	12.71	9.30	17.87	33.82	60.99

It will be seen that on the O section, to which no nitrogen is applied, the largest quantity of nitric nitrogen, in the first and second depths, is found in the plat that contains the largest quantity of total nitrogen, namely, plat O4, which is so fertile in the growth of the leguminous weed to which attention has been directed.

If we take the three depths (27 inches in all), we find that this plat shows over 23 pounds of nitric nitrogen per acre.

The poorest plat in nitric nitrogen is the plat which produces the smallest crops (O1). This contains less than 16 pounds of nitric nitrogen per acre in the three depths; plats O3 and O4 being intermediate.

If plat O4 (the leguminous-weed plat) be left out of account, we see that the plats manured with ammonium salts and with sodium nitrate (sections A and AA) are uniformly richer in nitric nitrogen than those of section O. But much richer in nitrates are the surface soils and higher subsoils of the rape-cake section, owing to abundant nitrification of accumulated nitrogenous organic matter. Richer still are the dunged plats. Plat 7 (1) contains nearly 15 pounds per acre of nitric nitrogen per acre in the surface soil (nearly 4¼ pounds more than any of the undunged plats), and is as rich as even the rape-cake plats in the second depth, and decidedly richer than even these in the third depth. The continuously dunged plat is much richer in the surface depth, and also in the second depth, and 6½ pounds per acre richer in the 27 inches. It would scarcely have been expected, even in the case of the continuously dunged plat, that so much nitric nitrogen would be found in February and March.

On the wheat plat similarly treated, only 56 pounds of nitric nitrogen per acre were found in October in the first 18 inches of soil. Here, in February and March, we have 33 pounds, or half the quantity, notwithstanding a wet winter. This would seem to indicate that nitrification must have begun early. On the other hand, the accumulated organic matter in the dunged soil must, by its absorptive power, render the dunged land less susceptible, pro rata, to loss by drainage, than the undunged plats, more of the rainfall being retained and dispersed by surface evaporation. On the Broadbalk plats, which are, as we know, pipe drained, the drainpipes often run freely on the undunged plats, while those on the dunged plats are giving no drainage water.

CHLORIN.

In the O series, without nitrogenous manure, the chlorin is greater in the superphosphated plats, Nos. 2 and 4, than in the others, the difference being especially marked in the third depth. The same thing is seen in the A series (ammonium salts). The explanation of this is not obvious. It can not be found in the introduction of chlorids to the soil, for the difference between the two sets of plats in chlorin contents is not great, although the O plats receive no direct addition of chlorids, except as slight impurities in the mineral fertilizers, beyond those derived from rain; while the plats of the A series usually receive annually about 56 pounds of chlorin per acre in their dressing of ammonium salts. It may be that the effect of the calcium in the superphosphate is to produce some physical difference in the soil which makes it more retentive of chlorids.

The quantity of chlorin present in the three aggregate depths, except on plat O4 and plat A2, does not differ much from that found in the most nearly corresponding plats in the Broadbalk wheat field.

PHOSPHORIC ACID AND POTASH.

A set of samples of the Hoos field barley plats was kindly drawn for me in the autumn of 1889 by Sir Henry Gilbert, for the purpose of investigations as far as regards their phosphoric acid and potash contents, as determined by the citric-acid process, on which I was then working. The samples represented the surface soil only, and were taken from only one place in each plat, as the immediate object was rather one of qualitative than of quantitative investigation. The results of the analyses have been fully discussed in an earlier paper, referred to on p. 96; but it may be convenient, for future reference, that the figures should find a place here.

PHOSPHORIC ACID.

The phosphoric acid results may be conveniently stated in the following table (Table 82), in which the plats are grouped with special reference to their phosphatic manuring, the corresponding plats of each section being brought together. The table shows the percentage of total phosphoric acid in the fine dry soil, and also the percentage dissolved by a 1 per cent solution of citric acid; and also the yield of barley (both grain and straw) in the year following the sampling.

TABLE 82.—*Hoos field barley soils, samples collected in the autumn of 1889—* PHOSPHORIC ACID *determinations.*

Series.	Plat.	Annual manuring since 1852.	Phosphoric acid in fine dry soil.		Yield per acre in 1890.	
			Total.	Dissolved by 1 per cent solution of citric acid.	Barley.	Straw.
			Per cent.	*Per cent.*	*Bushels.*	*Cwt.*
O	1	No manure	0.099	0.0055	13	6¼
A	1	Ammonia salts only	.097	.0060	24½	12⅜
AA	1	Nitrate of soda only	.104	.0067	29⅛	14⅕
AAS	1	Nitrate of soda and silicate of soda	.106	.0071	31¾	15⅗
		Average of above four plats	.102	.0063	24¾	12⅕
O	3	Potash, etc. (no phosphates)	.121	.0100	9¾	4¼
A	3	Ammonia salts, potash, etc. (no phosphates).	.102	.0081	23⅛	13⅕
AA	3	Nitrate of soda, potash, etc. (no phosphates).	.104	.0082	28	15⅕
AAS	3	Nitrate of soda, silicate of soda, potash, etc. (no phosphates).	.105	.0112	36⅛	19⅞
		Average of above four plats	.108	.0094	24⅝	13⅕

TABLE 82.—*Hoos field barley soils, etc.*—Continued.

Series.	Plat.	Annual manuring since 1852.	Phosphoric acid in fine dry soil.		Yield per acre in 1890.	
			Total.	Dissolved by 1 per cent solution of citric acid.	Barley.	Straw.
			Per cent.	*Per cent.*	*Bushels.*	*Cwt.*
O	2	Superphosphate only	.182	.0463	16¾	7⅛
A	2	Ammonia salts and superphosphate	.173	.0425	33½	16⅛
AA	2	Nitrate of soda and superphosphate	.165	.0350	47½	22¾
AAS	2	Nitrate of soda, silicate of soda, and superphosphate.	.180	.0475	46¼	22⅞
		Average of above four plats	.175	.0428	36	17⅛
O	4	Superphosphate, potash, etc	.189	.0538	17¾	7
A	4	Ammonia salts, superphosphate, potash, etc.	.182	.0500	46⅝	23¼
AA	4	Nitrate of soda, superphosphate, potash, etc.	.179	.0475	43¾	23⅜
AAS	4	Nitrate of soda, silicate of soda, superphosphate, potash, etc.	.169	.0479	46⅝	22⅛
		Average of above four plats	.180	.0498	38⅝	19¼
C	1	Rape cake only	.158	.0187	36	18⅛
C	3	Rape cake, potash, etc. (no phosphates)	.152	.0214	31¼	16½
C	2	Rape cake and superphosphate	.229	.0636	37¼	17⅞
C	4	Rape cake, superphosphate, potash, etc	.203	.0563	33⅛	15⅞
7	1	Farmyard manure for twenty years, unmanured for last eighteen years.	.134	.0206	22⅝	11¼
7	2	Farmyard manure for thirty-eight years	.176	.0447	53	29⅛

POTASH.

In the next table are shown the percentages of potash dissolved from the various soils by strong hydrochloric acid and also by a 1 per cent solution of citric acid, the plats in this case being grouped with special reference to their potash manuring.

TABLE 83.—*Hoos field barley soils, samples collected in the autum of 1889*—POTASH *determinations.*

Series.	Plat.	Annual manuring since 1852.	Potash in fine dry soil.		Yield per acre in 1890.	
			Dissolved by strong hydrochloric acid.	Dissolved by 1 per cent solution of citric acid.	Barley.	Straw.
			Per cent	*Per cent.*	*Bushels.*	*Cwt.*
O	1	No manure	0 183	0.0036	13	6¼
A	1	Ammonia salts only	.267	.0020	24½	12⅝
AA	1	Nitrate of soda only	.136	.0050	29½	14⅛
AAS	1	Nitrate of soda and silicate of soda	.193	.0042	31¾	15⅝
		Average of above four plats	.195	.0037	24¾	12⅛
O	2	Superphosphate only	.204	.0065	16¾	7⅛
A	2	Ammonia salts and superphosphate	.248	.0023	33½	16⅛
AA	2	Nitrate of soda and superphosphate	.142	.0038	47½	22¾
AAS	2	Nitrate of soda, silicate of soda, and superphosphate.	.188	.0035	46¼	22⅞
		Average of above four plats	.196	.0040	36	17⅛

TABLE 83.—*Hoos field barley soils, etc.*—Continued.

Series.	Plat.	Annual manuring since 1852.	Potash in fine dry soil.		Yield per acre in 1890.	
			Dissolved by strong hydrochloric acid.	Dissolved by 1 per cent solution of citric acid.	Barley.	Straw.
			Per cent.	*Per cent.*	*Bushels.*	*Cwt.*
O	3	Potash, etc. (no phosphates)	.318	.0366	9¾	4¼
A	3	Ammonia salts, potash, etc. (no phosphates)	.257	.0407	23⅛	13⅛
AA	3	Nitrate of soda, potash, etc. (no phosphates)	.239	.0350	28	15⅛
AAS	3	Nitrate of soda, silicate of soda, potash, etc. (no phosphates).	.230	.0454	36⅛	19⅞
		Average of above four plats	.261	.0394	24⅜	13⅛
O	4	Superphosphate, potash, etc	.300	.0340	17¾	7
A	4	Ammonia salts, superphosphate, potash, etc.	.326	.0298	46⅜	23¾
AA	4	Nitrate of soda, superphosphate, potash, etc.	.210	.0305	43¾	23⅞
AAS	4	Nitrate of soda, silicate of soda, superphosphate, potash, etc.	.250	.0270	46⅝	22⅛
		Averages of above four plats	.272	.0303	38⅝	19¼
C	1	Rape cake only	.170	.0079	36	18⅛
C	2	Rape cake and superphosphate	.194	.0079	37¼	17⅞
C	3	Rape cake, potash, etc. (no phosphate)	.219	.0351	31½	16½
C	4	Rape cake, superphosphate, potash, etc	.238	.0304	33½	15⅞
7	1	Farmyard manure for 20 years, unmanured for last 18 years.	.159	.0135	22⅜	11¼
7	2	Farmyard manure for 38 years	.167	.0321	53	29⅛

SECTION V.

HOOS FIELD LEGUMINOUS AND WHEAT-FALLOW SOILS.

INVESTIGATIONS SHOWING THE EFFECT OF VARIOUS LEGUMINOUS CROPS ON THE NITROGEN CONTENTS OF THE SOIL.

When referring to the Hoos field barley soils I drew your attention to a striking effect produced on the soil of a certain plat on which barley had been continuously grown for a very long period with full mineral fertilizers but without nitrogen. The nitrogen in the soil of this plat was found to be very appreciably greater than in the case of plats liberally treated with nitrogenous fertilizers, and the difference was shown to be due to the comparative encouragement given by the mineral fertilizers, in the absence of nitrogen supply, to a certain leguminous weed (*Medicago lupulina*) which is noticed to be extraordinarily prevalent among the barley on this plat.

In the same field there has been carried out over many years a most interesting set of experiments on leguminous crops, and also a continuous experiment on the growth of wheat on unmanured land, both year after year and in alternate years with intervening fallows. The examination of the soils from the various leguminous plats and from the wheat land has yielded results of great comparative interest.

The leguminous experiments were brought before you by Sir Henry Gilbert in 1893, and I should be apologetic for again discussing them but for the fact that the object of my own lectures would be conspicuously unfulfilled if they did not include the interesting analyses made from time to time of these particular soils from Hoos field; and I would add that the leguminous experiments have been, since Sir Henry Gilbert addressed you, followed by the growth of wheat on the same plats, with results to which we shall have to allude later. Abbreviating Sir Henry's account of the leguminous experiments, it may be stated that their object was to ascertain whether certain leguminous crops of different habits of growth, especially as to root range, could be successfully grown for a longer time and with a larger annual produce than others, all being similarly treated as regards fertilizers; and also to ascertain whether the success or failure of individual species would afford new evidence as to the source of the nitrogen of the Leguminosæ generally, and as to the causes of what is familiarly known as "clover sickness." The experiments were started in 1878, on land on which red clover had been grown, though with precarious success, for nearly thirty years. Of the plants originally chosen to succeed the clover several failed, and were discontinued, but others were successfully continued, notably *Trifolium repens* (white clover), *Vicia sativa* (vetches), *Melilotus leucantha* (Bokhara clover), and *Medicago sativa* (lucern). These crops were grown from 1878 down to 1898 in various series of plats, one series getting various mineral fertilizers only, while a second, third, and fourth series received respectively (in addition to various minerals as in the case of the first series) sodium nitrate, ammonium salts, and rape cake. In 1898 all but the plats of series 1 were plowed up, and wheat grown on them during 1899 and 1900. Series 1, however, is continued under leguminous cultivation.

This will probably be sufficient preface to the analytical soil results, to which attention is now to be drawn.

The samples analyzed were collected in 1881, 1882, and 1883 from the wheat-fallow land and from various leguminous plats of the series receiving annually only mineral fertilizers without any manurial supply of nitrogen.[1] It will be seen that in many cases samples have been taken down to twelve successive depths of 9 inches, i. e., to a depth in all of 9 feet. In these various samples both the organic nitrogen and the nitric nitrogen were determined. The full details of these analyses are given in the following table, the quantities being stated as percentages (parts per million in the case of the nitric nitrogen) and as pounds per acre.

We will first look at the organic-nitrogen results.

TABLE 84.—*Hoos field fallow wheat and leguminous land—Samples collected in 1881, 1882, 1883, and 1885—Organic* NITROGEN *results.*

ADOPTED WEIGHTS OF FINE DRY SOIL PER ACRE.

Depth.	Samples collected March, 1881.	Samples collected July 26-31, 1882.	Samples collected July 17-26, 1883.	Samples collected July 29-Aug. 14, 1885.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
First 9 inches	2,650,000	2,650,000	2,650,000	2,650,000
Second 9 inches	2,700,000	2,700,000	2,700,000	2,700,000
Third 9 inches	2,900,000	2,900,000	2,900,000	2,900,000
Fourth 9 inches		3,000,000	3,000,000	3,000,000
Fifth 9 inches		3,000,000	3,000,000	3,000,000
Sixth 9 inches		3,000,000	3,000,000	3,000,000
Seventh 9 inches			3,000,000	3,000,000
Eighth 9 inches			3,000,000	3,000,000
Ninth 9 inches			2,900,000	2,900,000
Tenth 9 inches			2,750,000	2,750,000
Eleventh 9 inches			2,750,000	2,750,000
Twelfth 9 inches			2,750,000	2,750,000
First 9 inches			2,650,000	2,650,000
Second 9 inches			2,700,000	2,700,000
Third to twelfth 9 inches			29,050,000	29,050,000
Total			34,400,000	34,400,000

[1] For full manurial details for the various plats, see the Rothamsted Memoranda.

TABLE 84.—*Hoos field fallow wheat, and leguminous land, etc.*—Continued.

NITROGEN IN FINE DRY SOIL.

Depth.	Samples collected March, 1881.		Samples collected July 26–31, 1882.			Samples collected July 17–26, 1883.				Samples collected July 29–Aug. 14, 1885.			
	Wheat-fallow land.	Leguminous land (series 1, plats 2 to 6).	Trifolium repens (series 1, plat 6).	Melilotus leucantha.		Wheat-fallow land.	Trifolium repens (series 1, plat 4).	Vicia sativa.		Wheat-fallow land.	Trifolium repens (series 1, plat 5).	Melilotus leucantha (series 1, plat 5).	Medicago sativa (series 1, plat 5).
				Series 1, plat 5.	Series 1, plat 6.			Series 1, plat 4.	Series 1, plat 6.				
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
First 9 inches	0.0969	0.1058	0.1140	0.1068	0.1149	0.1035	0.1128	0.1241	0.1140	0.1021	0.1269	0.1151	0.1219
Second 9 inches	.0606	.1633	.0652	.0625	.0652	.0629	.0738	.0792	.0616	.0605	.0816	.0690	.0710
Third 9 inches	.0552	.0579	.0439	.0578	.0455	.0533	.0674	.0637	.0448	.0486	.0705	.0622	.0624
Fourth 9 inches	.....	.....	.0379	.0495	.0466	.0458	.0633	.0582	.0337	.0475	.0557	.0300	.0505
Fifth 9 inches	.....	.....	.0373	.0545	.0435	.0472	.0523	.0543	.0286	.0465	.0406	.0300	.0373
Sixth 9 inches	.....	.....	.0405	.0561	.0372	.0503	.0610	.0490	.0325	.0402	.0396	.0510	.0556
Seventh 9 inches	.....	.....	.....	.....	.....	.1497	.0482	.0504	.0304	.0416	.0347	.0587	.0300
Eighth 9 inches	.....	.....	.....	.....	.....	.0424	.0657	.0440	.0350	.0436	.0349	.0349	.0347
Ninth 9 inches	.....	.....	.....	.....	.....	.0454	.0698	.0384	.0344	.0420	.0336	.0216	.0213
Tenth 9 inches	.....	.....	.....	.....	.....	.0428	.0703	.0431	.0320	.0400	.0298	.0189	.0200
Eleventh 9 inches	.....	.....	.....	.....	.....	.0491	.0671	.0422	.0487	.0438	.0474	.0196	.0132
Twelfth 9 inches	.....	.....	.....	.....	.....	.0542	.0460	.0453	.0447	.0461	.0363	.0205	.0068
First 9 inches	.....	.....	.....	.....	.....	.....	.....	.....	.....	.1021	.1269	.1151	.1219
Second 9 inches	.....	.....	.....	.....	.....	.....	.....	.....	.....	.0605	.0816	.0690	.0710
Mixture third to twelfth 9 inches	.....	.....	.....	.....	.....	.....	.....	.....	.....	.0449	.0439	.0386	.0350

NITROGEN PER ACRE.

	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
First 9 inches	2,568	2,804	3,021	2,830	3,045	2,743	2,989	3,289	3,021	2,706	3,363	3,050	3,230
Second 9 inches	1,636	1,709	1,760	1,688	1,760	1,698	1,993	2,138	1,663	1,634	2,203	1,863	1,917
Third 9 inches	1,601	1,679	1,273	1,676	1,320	1,546	1,955	1,847	1,299	1,409	2,045	1,804	1,810
Total first to third 9 inches	5,805	6,192	6,054	6,194	6,125	5,987	6,937	7,274	5,983	5,749	7,611	6,717	6,957
Fourth 9 inches	.....	.....	1,137	1,485	1,338	1,374	1,899	1,746	1,011	1,425	1,671	900	1,515
Fifth 9 inches	.....	.....	1,119	1,635	1,305	1,416	1,569	1,629	858	1,395	1,218	900	1,119
Sixth 9 inches	.....	.....	1,215	1,683	1,116	1,509	1,830	1,470	975	1,206	1,188	1,530	1,668
Total first to sixth 9 inches	.....	.....	9,525	10,997	9,884	10,286	12,235	12,119	8,827	9,775	11,688	10,047	11,259
Seventh 9 inches	.....	.....	.....	.....	.....	1,491	1,446	1,512	912	1,248	1,041	1,761	900
Eighth 9 inches	.....	.....	.....	.....	.....	1,272	1,971	1,320	1,050	1,308	1,047	1,047	1,041
Ninth 9 inches	.....	.....	.....	.....	.....	1,317	2,024	1,114	998	1,218	974	626	618
Tenth 9 inches	.....	.....	.....	.....	.....	1,177	1,933	1,185	880	1,100	820	520	550
Eleventh 9 inches	.....	.....	.....	.....	.....	1,350	1,845	1,161	1,339	1,205	1,303	539	363
Twelfth 9 inches	.....	.....	.....	.....	.....	1,491	1,265	1,246	1,229	1,268	943	564	187
Total seventh to twelfth 9 inches	.....	.....	.....	.....	.....	8,098	10,484	7,538	6,408	7,347	6,128	5,057	3,659
Total first to twelfth 9 inches	.....	.....	.....	.....	.....	18,384	22,719	19,657	15,235	17,122	17,816	15,104	14,918
First 9 inches	.....	.....	.....	.....	.....	.....	.....	.....	.....	2,706	3,363	3,050	3,230
Second 9 inches	.....	.....	.....	.....	.....	.....	.....	.....	.....	1,634	2,203	1,863	1,917
Mixture third to twelfth 9 inches	.....	.....	.....	.....	.....	.....	.....	.....	.....	13,043	12,753	11,213	10,168
Total	.....	.....	.....	.....	.....	.....	.....	.....	.....	17,383	18,319	16,126	15,315

It will be remembered that all the soils here are in the same field, and probably therefore originally more or less alike.

We see that in the first 9 inches the leguminous soils are uniformly very markedly richer in nitrogen than the wheat-fallow soils. The same thing is in nearly every case shown in the second 9 inches, and for the most part also in the third 9 inches.

If we look at the line in the lower part of the table showing the nitrogen per acre for the aggregate first three depths (1 to 27 inches), the nitrogen accumulation in the leguminous land, as compared with the wheat land, assumes large and very striking dimensions, except on one plat (*Vicia sativa*, plat 6, 1883), where there appears to be throughout some irregularity of subsoil. Even here, however, the accumulation is well seen in the surface soil.

In some plats the influence of the vegetation appears to be recognizable lower still, but the natural irregularities of the lower subsoil render it impossible here to draw certain conclusions. But the general evidence of accumulation in the upper layers is most clear and convincing, and accords admirably with modern knowledge of the life history and functions of leguminous crops—knowledge which was but dimly foreseen, although its advancing shadow was felt when these experiments were started. It was not until 1886 that Hellriegel announced the results which gave definite shape and direction to the long-vexed problem relating to the sources of the nitrogenous food of this highly interesting natural order of plants.

In the first 27 inches of soil we find that the ten sets of samples representing the leguminous plats average 6,604 pounds of total nitrogen per acre, while the three sets of wheat soils average but 5,847 pounds, showing an average gain of 757 pounds of nitrogen per acre under the influence of leguminous vegetation. Sir Henry Gilbert, in his lectures, further pointed out that the annual output of nitrogen in the crops had been far greater on the leguminous land. During the twenty-seven years before the miscellaneous leguminous crops were first planted, and when the leguminous land was under red clover, it yielded in its clover crops a yearly average of 32 pounds of nitrogen per acre, as against 15 pounds per acre yielded in the crops of the wheat and fallow land, while during the following fourteen years of various leguminous herbage the average yearly output of nitrogen in crops was 14 pounds per acre for the red-clover plat, 24 pounds for the white clover, 75 pounds for the vetches, 58 pounds for the Bokhara clover, and no less than 137 pounds for the lucern. During the same time the wheat and fallow land yielded only 12 pounds of nitrogen per acre per annum in its crops. No nitrogen was manurially applied on any of these plats.

We have, therefore, not only soil accumulation in the root residues, but also a great output of organic nitrogen in the crops (varying with the species and habits of the individual Leguminosæ grown), a large part of which nitrogen must undoubtedly have been due to the fixation of atmospheric nitrogen.

Table 85 shows the corresponding figures for the nitrogen existing as nitric acid, or rather as nitrates; and here subsoil irregularities do not interfere with our grasp of the facts, for the nitrates, being soluble and migratory, are in a diffused form, and (unlike the organic nitrogen) are not much affected by the variations in the mineral composition (proportions of clay, stones, and chalk) of the subsoil.

TABLE 85.—*Hoos field fallow wheat and leguminous land—Samples collected in 1881, 1882, 1883, and 1885*—NITROGEN *existing as nitrates.*

ADOPTED WEIGHTS OF FINE DRY SOIL PER ACRE.

Depth.	Samples collected March, 1881.	Samples collected July 26–31, 1882.	Samples collected July 17–26, 1883.	Samples collected July 29–Aug. 14, 1885.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
First 9 inches	2,650,000	2,650,000	2,650,000	2,650,000
Second 9 inches	2,700,000	2,700,000	2,700,000	2,700,000
Third 9 inches	2,900,000	2,900,000	2,900,000	2,900,000
Fourth 9 inches	......	3,000,000	3,000,000	3,000,000
Fifth 9 inches	......	3,000,000	3,000,000	3,000,000
Sixth 9 inches	......	3,000,000	3,000,000	3,000,000
Seventh 9 inches	......	......	3,000,000	3,000,000
Eighth 9 inches	......	......	3,000,000	3,000,000
Ninth 9 inches	......	......	2,900,000	2,900,000
Tenth 9 inches	......	......	2,750,000	2,750,000
Eleventh 9 inches	......	......	2,750,000	2,750,000
Twelfth 9 inches	......	......	2,750,000	2,750,000
First 9 inches	......	......	2,650,000	2,650,000
Second 9 inches	......	......	2,700,000	2,700,000
Third to twelfth 9 inches	......	......	29,050,000	29,050,000
Total	......	......	34,400,000	34,400,000

NITROGEN AS NITRATES, PARTS PER MILLION OF FINE DRY SOIL.

Depth.	Samples collected March, 1881.		Samples collected July 26–31, 1882.			Samples collected July 17–26, 1883.				Samples collected July 29–Aug. 14, 1885.			
				Melilotus leucantha.				Vicia sativa.					
	Wheat-fallow land.	Leguminous land (series 1, plats 2-6).	Trifolium repens (series 1, plat 6).	Series 1, plat 5.	Series 1, plat 6.	Wheat-fallow land.	Trifolium repens (series 1, plat 4).	Series 1, plat 4.	Series 1, plat 6.	Wheat-fallow land.	Trifolium repens (series 1, plat 5).	Melilotus leucantha (series 1, plat 5).	Medicago sativa (series 1, plat 5).
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
First 9 inches	2.66	4.51	3.24	1.48	1.28	7.35	11.445	4.505	3.785	6.46	4.26	1.61	3.29
Second 9 inches	1.24	3.07	1.10	.67	.36	2.98	10.27	1.52	1.01	1.36	.51	.52	.41
Third 9 inches	1.08	6.33	.66	.31	.21	.85	2.91	.47	.37	.95	.31	.73	.27
Fourth 9 inches	......	......	1.03	.26	.33	.90	2.545	9.555	.505	.72	.62	.98	.27
Fifth 9 inches	......	......	1.46	.37	.28	.54	3.025	1.525	.835	.56	2.36	1.74	.33
Sixth 9 inches	......	......	1.72	.70	.55	1.19	2.925	2.125	1.475	.49	3.77	2.07	.31
Seventh 9 inches	......	......	......	......	......	1.28	2.64	2.385	1.505	.59	4.38	2.65	.19
Eighth 9 inches	......	......	......	......	......	.76	2.78	1.985	1.64	.61	4.21	3.36	.27
Ninth 9 inches	......	......	......	......	......	.51	2.85	1.565	1.66	.79	3.86	3.33	.24
Tenth 9 inches	......	......	......	......	......	.64	3.62	1.935	1.875	.73	3.89	3.33	.22
Eleventh 9 inches	......	......	......	......	......	1.07	3.33	2.06	2.325	.72	4.03	3.21	.16
Twelfth 9 inches	......	......	......	......	......	.67	3.445	1.935	2.35	.75	3.62	3.68	.15
First 9 inches	......	......	......	......	......	......	......	......	......	6.46	4.26	1.61	3.29
Second 9 inches	......	......	......	......	......	......	......	......	......	1.36	.51	.52	.41
Mixture third to twelfth 9 inches	......	......	......	......	......	......	......	......	......	.71	3.03	2.52	.24

TABLE 85.—*Hoos field fallow wheat and leguminous land, etc.*—Continued.

NITROGEN AS NITRATES, PER ACRE.

Depth.	Samples collected March, 1881.		Samples collected July 26–31, 1882,			Samples collected July 17–26, 1883.				Samples collected July 29–Aug. 14, 1885.			
	Wheat-fallow land.	Leguminous land (series 1, plats 2–6).	Trifolium repens (series 1, plat 6).	Melilotus leucantha.		Wheat-fallow land.	Trifolium repens (series 1, plat 4).	Vicia sativa.		Wheat-fallow land.	Trifolium repens (series 1, plat 5).	Melilotus leucantha (series 1, plat 5).	Medicago sativa (series 1, plat 5).
				Series 1, plat 5.	Series 1, plat 6.			Series 1, plat 4.	Series 1, plat 6.				
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
First 9 inches	7.05	11.95	8.59	3.92	3.39	19.48	30.33	11.94	10.03	17.12	11.29	4.27	8.72
Second 9 inches	3.35	8.29	2.97	1.81	.97	8.05	27.73	4.11	2.72	3.67	1.38	1.40	1.11
Third 9 inches	3.13	18.36	1.91	.90	.61	2.47	8.44	1.37	1.08	2.76	.90	2.12	.78
Total first to third 9 inches	13.53	38.60	13.47	6.63	4.97	30.00	66.50	17.42	13.83	23.55	13.57	7.79	10.61
Fourth 9 inches	------	------	3.09	.78	.99	2.70	7.64	1.67	1.52	2.16	1.86	2.94	.81
Fifth 9 inches	------	------	4.38	1.11	.84	1.62	9.07	4.58	2.51	1.68	7.08	5.22	.99
Sixth 9 inches	------	------	5.16	2.10	1.65	3.57	8.77	6.37	4.42	1.47	11.31	6.21	.93
Total first to sixth 9 inches	------	------	26.10	10.62	8.45	37.89	91.98	30.04	22.28	28.86	33.82	22.16	13.34
Seventh 9 inches	------	------	------	------	------	3.84	7.92	7.16	4.52	1.77	13.14	7.95	.57
Eighth 9 inches	------	------	------	------	------	2.28	8.34	5.95	4.92	1.83	12.63	10.08	.81
Ninth 9 inches	------	------	------	------	------	1.48	8.27	4.54	4.81	2.29	11.19	9.66	.70
Tenth 9 inches	------	------	------	------	------	1.76	9.95	5.32	5.14	2.01	10.70	9.16	.61
Eleventh 9 inches	------	------	------	------	------	2.91	9.16	5.66	6.40	1.98	11.08	8.83	.44
Twelfth 9 inches	------	------	------	------	------	1.84	9.51	5.32	6.46	2.06	9.96	10.12	.41
Total seventh to twelfth 9 inches	------	------	------	------	------	14.14	53.15	33.95	32.25	11.94	68.70	55.80	3.54
Total first to twelfth 9 inches	------	------	------	------	------	52.03	145.13	63.99	54.53	40.80	102.52	77.96	16.88
First 9 inches	------	------	------	------	------	------	------	------	------	17.12	11.29	4.27	8.72
Second 9 inches	------	------	------	------	------	------	------	------	------	3.67	1.38	1.40	1.11
Mixture third to twelfth 9 inches	------	------	------	------	------	------	------	------	------	20.63	88.02	73.21	6.97
Total	------	------	------	------	------	------	------	------	------	41.42	100.69	78.88	16.80

Exigencies of space will not allow of a thorough discussion of the results in all their detail, but the principal deductions from them can be made clear by examination of some selected plats. Primarily the most interesting are the wheat-fallow plats and the *Trifolium repens* (white clover) plats, sampled in 1883 and 1885. If we take the total twelve depths (9 feet) of soil and subsoil, we find that the wheat-fallow plats contained in the form of nitrates, in round numbers, 52 pounds and 41 pounds per acre, while the white-clover plats, the same depth, about 145 pounds and 102 pounds. On the average the clover plats showed not far short of three times as much nitric nitrogen as the wheat-fallow land.

Clearly this enormous difference is to be correlated with the much larger quantity of organic nitrogen found in the clover soil, owing to accumulated root residue, there being not only more nitrogen to become nitrified, but the excess of organic matter being more favorable (as it is within certain limits and in presence of lime) to the activity of the nitrifying process.

It is, however, to be noted that this excess of nitrates on the clover plats does not by any means indicate the whole extent of this greater nitrification, for leguminous plants, like cereals, absorb and utilize nitrates freely. But white clover, being but a shallow rooting plant, can not directly utilize nitrates which have descended below the surface soil, and so we find a great accumulation in the subsoil. It is for this reason that the white-clover plats serve so well to show us evidence of the activity of nitrification going on in them.

When we examine the more heavily cropping and more deeply rooting plants—vetches and Bokhara clover—we find in the subsoils far less nitrates. Probably more nitrates have actually been produced, but a smaller quantity has been left unutilized. For instance, in 1883, the vetch plats show (in 9 feet) only about 34 pounds and 32 pounds of nitritic nitrogen per acre, as against 53 pounds in the white-clover plat; and in 1885 the Bokhara clover shows only about 56 pounds per acre, as against nearly 69 pounds on the white-clover plat.

But the most remarkably interesting plat is the lucern plat. Lucern, as you are aware, is a very deeply rooting plant, sending down stout roots for many feet into the subsoil. So thoroughly has this crop utilized the nitrates formed in the surface soil that we find scarcely a pound of nitrogen per acre in any depth below the second, the total quantity of nitric nitrogen found to a depth of 9 feet being less than 17 pounds per acre, as against 102 pounds in the neighboring white-clover plat.

It is now interesting to inquire how far the accumulation of nitrogen in these soils under the influence of the leguminous vegetation can be practically shown to influence their potential fertility for subsequent crops. It has long been accepted that a clover crop acts as a manurial dressing for the following wheat crop, and our modern methods of farming are being more and more attuned to the more definite recent teachings of science on the value of the Leguminosæ as reinforcers of soil nitrogen. It has been said that in 1898 three of the four series of these leguminous experimental plats were plowed up and put into wheat. Crops of wheat were taken in both 1899 and 1900. The following table shows the crops yielded on land that had been previously occupied by seven descriptions of leguminous crops in both years, and also the crops grown on the unmanured alternate wheat and fallow land of the same field, not only during the same seasons but in preceding years. The last-named results are stated in two ways, one giving the actual yield per acre of the bearing half of the land, the other the total yield per acre when the fallow half is also reckoned in the wheat area. The average yield of the unmanured wheat plat in Broadbalk field is also given for comparison, and a summary of all the foregoing data is appended at the foot of the table.

TABLE 86.—*Produce of wheat at Rothamsted under various conditions of soil.*

	Dressed grain.		Total grain per acre.	Total straw per acre.	Total produce (grain and straw) per acre.
	Produce per acre.	Weight per bushel.			
Wheat after various leguminous plants, harvest 1899.	*Bushels.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Lucern	39¼	63.6	2,609	5,499	8,108
Peas	42½	63.9	2,808	5,622	8,430
Bokhara clover	43¾	64.1	2,916	5,592	8,508
Sainfoin	45¼	64.3	3,028	5,611	8,639
White clover	43½	64.1	2,904	5,404	8,308
Red clover	43	64.3	2,925	5,580	8,505
Vetches	40	64.4	2,715	5,051	7,766
Mean	42½	64.1	2,843	5,480	8,323
Wheat after various leguminous plants, second season, harvest 1900.					
Lucern	26½	61.7	1,677	2,614	4,291
Peas	14¼	61.0	890	1,312	2,202
Bokhara clover	16½	61.4	1,033	1,549	2,582
Sainfoin	19	61.4	1,198	1,788	2,986
White clover	19¼	61.5	1,220	1,707	2,927
Red clover	19	61.5	1,205	1,787	2,992
Vetches	14¼	61.9	902	1,360	2,262
Mean	18⅜	61.5	1,161	1,731	2,892
Wheat alternated with fallow (produce reckoned at the yield per acre of the half in crop each year).					
Average 40 years, 1856-1895	17⅞	58.7	1,073	1,595	2,668
1896	16	60.7	1,020	1,312	2,332
1897	7	59.5	460	710	1,170
1898	20¼	61.3	1,314	2,650	3,964
1899	15¾	62.2	1,004	1,616	2,620
1900	11⅝	60.7	751	1,050	1,801
Mean, 5 years, 1896-1900	14⅛	60.9	910	1,467	2,377
Wheat alternated with fallow (yield per acre of the whole area, half in crop and half fallow).					
Average 40 years, 1856-1895	8⅞	58.7	536	798	1,334
1896	8	60.7	510	656	1,166
1897	3½	59.5	230	355	585
1898	10⅛	61.3	657	1,325	1,982
1899	7⅞	62.2	502	808	1,310
1900	6	60.7	376	525	901
Mean, 5 years, 1896-1900	7	60.9	455	734	1,189
Wheat grown continuously without manure (Broadbalk field).					
Average 40 years, 1856-1895	12¾	58.8	795	1,127	1,921
1896	16⅞	61.4	1,087	1,309	2,396
1897	8¾	60.3	592	867	1,459
1898	12	61.4	823	1,363	2,186
1899	12	61.7	769	1,056	1,825
1900	12¼	60.2	769	1,008	1,777
Mean, 5 years, 1896-1900	12⅜	61.0	808	1,121	1,929

SUMMARY.

Wheat after various leguminous plants:					
First season, harvest 1899	42½	64.1	2,843	5,480	8,323
Second season, harvest 1900	18⅜	61.5	1,161	1,731	2,892
Wheat alternated with fallow, average 40 years, 1856-1895:					
Produce per acre of the half in crop each year	17⅞	58.7	1,073	1,595	2,668
Produce per acre of the whole area, half in crop and half fallow	8⅞	58.7	536	798	1,334
Wheat grown continuously without manure, Broadbalk field, average 40 years, 1856-1895	12¾	58.8	795	1,127	1,921

The fertility of the recently broken up leguminous land is very strongly brought out in the 1899 crop. The yield in 1900 was much smaller than might have been expected from land which in 1899 was in such a high state of fertility; but the winter of 1899–1900 was exceedingly wet, and resulted in the washing away from the surface soil of a very large proportion of the nitrates formed during the autumn. In the Broadbalk field, where the subsoil is tapped by drain-pipes which enable the drainage water to be systematically collected and analyzed, this heavy loss of nitrates through autumn and winter drainage was very clearly noted by the examination of the various samples of drainage water collected. This loss no doubt accounts for the comparative poverty of the crop of 1900 as compared with that of 1899, though even then the richness of the soil as compared with that of the unmanured wheat plats is very evident.

Section VI.

BARN FIELD ROOT-CROP SOILS.

The experiments on the continuous growth of root crops in Barn field have been also fully laid before you by Sir Henry Gilbert,[1] and I have only to add the results obtained by the chemical examination of a series of soil samples drawn from this field in the year 1870, after fourteen years' continuous growth of Swedish turnips under various conditions of fertilization. The system of the experiments, however, should be briefly described.

The plats I have to refer to constitute four series or sets of 7 plats each. Plat 1 in each series has received annually a dressing of farmyard manure, plat 2 in each series has also received farmyard manure but with superphosphate in addition. Plat 3 in each series has received no mineral or general manure. Plats 4, 5, and 6 in each series have received each year superphosphate with or without dressings of potassium salts and other alkaline salts during part of the period (see table); while plat 7 of each series has received throughout superphosphate with, during a portion of the period, ammonium sulphate and alkaline salts.

The plats in series 1 receive only the fertilizers aforesaid; but in series 2 all received in addition, for five years, a mixture of sawdust and nitric acid, and for the remaining nine years an annual dressing of sodium nitrate.

In series 3 all the plats, in addition to the general manures, received ammonium salts.

In series 4 all in earlier years received ammonium salts, supplemented by sawdust, and in later years a heavy dressing of both ammonium salts and rape cake. While the plats of series 5 having in earlier years received sawdust, in later years received a heavy dressing of rape cake, but without ammonium salts.

All the crops, both roots and leaves, were annually removed from the land.

The following table, abbreviated from the Rothamsted Memoranda, gives the average annual produce of roots (neglecting the leaves or tops) for fifteen years, including the year after the soil samples were taken:

---

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. No. 22.

TABLE 87.—*Swedish turnips in Barn field, Rothamsted—Average annual crop per acre (bulbs only) for fifteen seasons, 1856–1870.*

Plat.	Standard manures.	Series 1, standard manures only.		Standard manures and cross dressed with— Series 2, 5 years, 1856–1860, 3,000 pounds sawdust and 328 pounds nitric acid; 10 years, 1861–1870, 550 pounds sodium nitrate.		Series 3, 5 years, 1856–1860, 200 pounds ammonium salts; 10 years, 1861–1870, 400 pounds ammonium salts.		Series 4, 5 years, 1856–1860, 200 pounds ammonium salts and 3,000 pounds sawdust; 10 years, 1861–1870, 400 pounds ammonium salts and 2,000 pounds rape cake.		Series 5, 5 years, 1856–1860, 3,000 pounds sawdust; 10 years, 1861–1870, 2,000 pounds rape cake.	
		Tons.	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
1	Farmyard manure	6	4	7	9	8	8	8	16	8	0
2	Farmyard manure and superphosphate	6	7	7	13	8	3	8	14	7	16
3	No mineral manure	0	11	0	19	0	13	3	6	3	8
4	Superphosphate each year; mixed alkaline salts, 1856–60	2	16	5	2	4	12	6	12	5	8
5	Superphosphate each year	2	12	4	13	3	16	5	16	5	0
6	Superphosphate each year; potassium sulphate, 1856–60	2	7	4	11	4	5	6	6	5	3
7	Superphosphate each year; potassium sulphate and ammonium salts, 1856–60	2	12	4	13	4	12	6	15	5	9
	Mean of plats 4, 5, and 6	2	12	4	15	4	4	6	4	5	3

Samples of the soils taken toward the close of the period above included, and representing the first three depths of 9 inches each, were examined as regards their contents of total nitrogen, with the following results:

TABLE 88.—*Barn field root-crop land, samples collected in April, 1870, after fourteen years of Swedish turnips, 1856–1869 (a)*—NITROGEN *in fine, dry soil.*

Plat.	Standard manures.	Series 1, standard manures only.	Standard manures and cross dressed with— Series 2, 5 years, 1856–1860, 3,000 pounds sawdust and 328 pounds nitric acid; 10 years, 1861–1870, 550 pounds sodium nitrate.	Series 3, 5 years, 1856–1860, 200 pounds ammonium salts; 10 years, 1861–1870, 400 pounds ammonium salts.	Series 4, 5 years, 1856–1860, 200 pounds ammonium salts and 3,000 pounds sawdust; 10 years 1861–1870, 400 pounds ammonium salts and 2,000 pounds rape cake.	Series 5, 5 years, 1856–1860, 3,000 pounds sawdust; 10 years, 1861–1870, 2,000 pounds rape cake.
	First 9 inches.	*Per ct.*	*Per cent.*	*Per ct.*	*Per cent.*	*Per ct.*
1	Farmyard manure	0.1449	0.1501	0.1512	0.1693	0.1592
2	Farmyard manure and superphosphate	.1438	.1398	.1511	.1470	.1474
3	No mineral manure	.0880	.0964	.0920	.1010	.1083
4	Superphosphate each year; mixed alkaline salts, 1856–1860	.0934	.0998	.0949	.1061	.1036
5	Superphosphate each year	.0888	.0960	.0936	.1056	.1041
6	Superphosphate each year; potassium sulphate, 1856–1860	.0867	.0900	.0942	.1029	.0972
7	Superphosphate each year; potassium sulphate and ammonium salts, 1856–1860	.0974	.0924	.0954	.1035	.0997
	Second 9 inches.					
1	Farmyard manure	.0660	.0701	.0729	.0715	.0699
2	Farmyard manure and superphosphate	.0727	.0736	.0796	.0592	.0670
3	No mineral manure	.0629	.0727	.0698	.0593	.0670
4	Superphosphate each year; mixed alkaline salts, 1856–1860	.0782	.0707	.0629	.0671	.0661
5	Superphosphate each year	.0685	.0691	.0625	.0691	.0634
6	Superphosphate each year; potassium sulphate, 1856–1860	.0622	.0643	.0728	.0660	.0637
7	Superphosphate each year; potassium sulphate and ammonium salts, 1856–1860	.0837	.0600	.0693	.0612	.0668
	Third 9 inches.					
1	Farmyard manure	.0584	.0640	.0582	.0570	.0585
2	Farmyard manure and superphosphate	.0582	.0618	.0609	.0458	.0544
3	No mineral manure	.0573	.0546	.0592	.0480	.0577
4	Superphosphate each year; mixed alkaline salts, 1856–1860	.0630	.0549	.0473	.0539	.0538
5	Superphosphate each year	.0694	.0646	.0481	.0551	.0483
6	Superphosphate each year; potassium sulphate, 1856–1860	.0674	.0456	.0652	.0567	.0541
7	Superphosphate each year; potassium sulphate and ammonium salts, 1856–1860	.0836	.0484	.0590	.0526	.0630

SUMMARY.

	Series 1	Series 2	Series 3	Series 4	Series 5
Means of plats 4, 5, and 6:					
First 9 inches	0.0896	0.0953	0.0942	0.1049	0.1016
Second 9 inches	.0696	.0680	.0661	.0674	.0644
Third 9 inches	.0666	.0550	.0535	.0552	.0521
Mean	.0753	.0728	.0713	.0758	.0727

a The crops of 1859 and 1860 failed and were plowed in.

It will suffice to direct your attention specifically to the results for the first 9 inches or surface soils, and the figures may be simplified by averaging the three plats—4, 5, and 6—the treatment of which has been somewhat similar.

It is now well recognized that root crops grown with mineral manures alone perhaps exhaust the available nitrogen of the surface soil more than any other crops, and if we look at the results for plats 4, 5, and 6 we find that in the surface samples of the first series, where nothing but mineral manure is used, there is on the average (see summary at foot of Table 88) 0.0896 per cent of nitrogen. Compared with those soils of the wheat or barley land on which mineral manures only are used, this percentage of nitrogen is decidedly low, while at the same time the annual yield of nitrogen in the root crops under the influence of mineral manure alone is decidedly greater than that in the cereal crops.

When the same three plats have been annually supplied with sodium nitrate, as in series 2, we at once see a very tangible increase in the proportion of nitrogen, there being found (see summary) on the average 0.0953 per cent of nitrogen on these plats, as against 0.0896 per cent in series 1.

In series 3, where a like quantity of nitrogen has been regularly supplied in the form of ammonium salts, we get almost the same average result as with the sodium nitrate, namely, 0.0942 per cent.

In series 4 and series 5, on which rape cake has been abundantly applied, there is throughout a further increase in nitrogen, the average percentages in the three plats being 0.1049 in series 4 and 0 1016 in series 5.

We know that neither ammonium salts nor nitrates accumulate in the soil, and no doubt, therefore, the increased quantity of nitrogen in series 1 and series 2 is due to accumulated crop residues, corresponding to the increased growth shown in the preceding table.

On series 4 and series 5 there has also been greater growth and more root residue, but the increased proportion of nitrogen may be due not merely to this, but also to some extent to accumulation of manurial nitrogen derived from the rape cake.

It will be further noticed that on the three plats—4, 5, and 6—the proportion of nitrogen is greater in series 4, where the rape cake has been supplemented by ammonium salts, than in series 5, where the rape cake has not been so supplemented, and if we refer to the previous table, showing the average crop results, it will be seen that plats 4, 5, and 6 in series 4 show throughout very considerably larger average crops than in series 5.

In the case of the plat which has received no mineral manure the effect of the varied treatment in the different series is also shown in the results of the soil analyses.

Although there have not been large crop residues in series 2 and series 3 to reenforce the natural nitrogen, there have been, as will be seen on reference to Table 87, throughout but small crops, and therefore small demands upon the soil nitrogen, whether natural or manurially supplied.

On the plats receiving farmyard manure (plats 1 and 2) the nitrogen is throughout, as we should expect, far greater in proportion in every series than on the other plats, the largest quantities of nitrogen being found in series 4 and series 5, in which the dressings of farmyard manure have been supplemented by dressings of rape cake.

SECTION VII.

AGDELL FIELD EXPERIMENTAL ROTATION SOILS.

It will be appropriate next to consider the results of the analyses which have been made of soils collected from the Agdell rotation field; but first the nature of the experiments must be briefly recalled to you.

The experiments began in 1848. One-third of the land has been continuously unmanured; one-third, during the time with which we are here concerned, was manured with superphosphate once every four years (namely, for the turnip crop commencing each rotation), while one-third has been (also once in each rotation, namely, for the turnip crop) treated with a complex mixture of mineral and nitrogenous fertilizers, including phosphates, potassium, sodium, and magnesium salts, ammonium salts, and rape cake—hereafter referred to as "mixed manure." On one-half of each of the three differently manured plats the turnip crop, both roots and leaves, has been annually carted or removed from the field, while on the other half the turnips have been either consumed on the plats by sheep or spread and plowed in. The rotation followed has been turnips, barley, clover (or beans), and wheat; but on one-half of each rotation plat only has clover or beans been sown, the other half forming a bare fallow.

We have therefore really, for each system of manuring, four rotations, namely, as follows:

Turnips (carted), barley, clover, wheat.
Turnips (fed on the land) barley, clover, wheat.
Turnips (carted), barley, fallow, wheat.
Turnips (fed on the land), barley, fallow, wheat.

It is obviously a matter of interest to consider how far, over a number of years, the carting or consumption of the turnips on the one hand or the growth of leguminous vegetation on the other, as compared with fallow, affected the nitrogen contents of the soil.

The samples of the soil were collected in 1867, at the end of twenty years, or five complete rotations; again in 1874, after twenty-seven years, or not quite seven rotations; and again in 1883 and 1884, after thirty-six years, or nine complete rotations.

Two tables are here given, showing the nitrogen contents found at these various periods in the surface soils of the various plats. One table gives the quantities of nitrogen stated as percentages in the surface soil, the other in pounds per acre for the first 9 inches.

It will be seen that each table gives the results in two forms. On the left-hand side of the tables the analytical results are so arranged as to afford for each set of rotations (unmanured, superphosphate, and mixed manure) an easy comparison between the nitrogen found in the plats from which the turnips, both roots and tops, have been annually removed or carted, and that found in the plats on which the roots have been consumed by sheep or, in some cases, chopped up and returned to the land. The right-hand side of the tables rearranges the same results in such a way as to allow us easily to compare in each series of rotation those portions of the plats on which leguminous crops (beans or clover) have been grown in the intervals between the barley and wheat, and the corresponding portions which have been allowed to remain fallow during this stage of the rotation.

TABLE 89.—*Agdell field experimental rotation land—Soil samples collected in 1867 (after wheat), 1874 (after clover), and 1883–84 (after wheat)—Percentages of* NITROGEN *in fine, dry soil of first 9 inches.*

	Plat.	Samples collected in— Nov., 1867 (after wheat).	Oct., 1874 (after clover).	Nov., 1883, to Jan., 1884 (after wheat).	Mean.
UNMANURED.					
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Fallow:					
Roots carted	21–22	0.1303	0.1297	0.1230	0.1277
Roots fed	17–18	.1233	.1165	.1135	.1178
Mean		.1268	.1230	.1183	.1228
Beans or clover:					
Roots carted	23–24	.1303	.1378	.1308	.1330
Roots fed	19–20	.1297	.1187	.1205	.1230
Mean		.1300	.1283	.1257	.1280
Mean of all		.1284	.1257	.1220	.1254
Carted:					
Fallow	21–22	.1303	.1297	.1230	.1277
Beans or clover	23–24	.1303	.1378	.1308	.1330
Mean		.1303	.1338	.1269	.1303
Fed:					
Fallow	17–18	.1233	.1165	.1135	.1178
Beans or clover	19–20	.1297	.1187	.1205	.1230
Mean		.1265	.1176	.1170	.1204
Mean of all		.1284	.1257	.1220	.1254
SUPERPHOSPHATE.					
Fallow:					
Roots carted	13–14	0.1224	0.1147	0.1161	0.1177
Roots fed	9–10	.1240	.1126	.1228	1198
Mean		.1232	.1137	.1195	.1188
Beans or clover:					
Roots carted	15–16	.1327	.1241	.1207	.1258
Roots fed	11–12	.1380	,1321	.1296	.1322
Mean		.1354	.1281	.1252	.1295
Mean of all		.1293	.1209	.1223	.1242

TABLE 89.—*Agdell field experimental rotation land, etc.*—Continued.

SUPERPHOSPHATE—Continued.

	Plat.	Samples collected in—			Mean.
		Nov., 1867 (after wheat).	Oct., 1874 (after clover).	Nov., 1883, to Jan., 1884 (after wheat).	
Carted:		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Fallow	13-14	0.1224	0.1147	0.1161	0.1177
Beans or clover	15-16	.1327	.1241	.1207	.1258
Mean	....	.1276	.1194	.1184	.1218
Fed:					
Fallow	9-10	.1240	.1126	.1228	.1198
Beans or clover	....	.1380	.1321	.1296	.1332
Mean	....	.1310	.1224	.1262	.1265
Mean of all	....	.1293	.1209	.1223	.1242

MIXED MANURE.

Fallow:					
Roots carted	5-6	0.1254	0.1203	0.1216	0.1224
Roots fed	1-2	.1232	.1225	.1244	.1267
Mean	....	.1293	.1214	.1230	.1246
Beans or clover:					
Roots carted	7-8	.1266	.1290	.1255	.1270
Roots fed	3-4	.1331	.1372	.1420	.1374
Mean	....	.1298	.1331	.1338	.1322
Mean of all	....	.1296	.1273	.1284	.1284
Carted:					
Fallow	5-6	.1254	.1203	.1216	.1224
Beans or clover	7-8	.1266	.1290	.1255	.1270
Mean	....	.1260	.1247	.1236	.1248
Fed:					
Fallow	1-2	.1332	.1225	.1244	.1267
Beans or clover	3-4	.1331	.1372	.1420	.1374
Mean	....	.1332	.1299	.1332	.1321
Mean of all	....	.1296	.1273	.1284	.1284

SUMMARY.

Unmanured	....	0.1284	0.1257	0.1220	0.1254
Superphosphate	....	.1293	.1209	.1223	.1242
Mixed manure	....	.1296	.1273	.1284	.1284

TABLE 90.—*Agdell field experimental rotation land—Soil samples collected in 1867 (after wheat), 1874 (after clover), and 1883–84 (after wheat)*—NITROGEN *per acre in fine dry soil of first 9 inches.*

UNMANURED.

	Plats.	Samples collected in—			Mean.
		November, 1867 (after wheat).	October, 1874 (after clover).	November, 1883, to January, 1884 (after wheat).	
		Pounds per acre.	*Pounds per acre.*	*Pounds per acre.*	*Pounds per acre.*
Fallow:					
Roots carted	21 and 22	3,127	3,113	2,952	3,064
Roots fed	17 and 18	2,959	2,976	2,724	2,826
Mean		3,043	2,955	2,838	2,945
Beans or clover:					
Roots carted	23 and 24	3,127	3,307	3,139	3,191
Roots fed	19 and 20	3,113	2,849	2,892	2,951
Mean		3,120	3,078	3,016	3,071
Mean of all		3,082	3,016	2,927	3,008
Carted:					
Fallow	21 and 22	3,127	3,113	2,952	3,064
Beans or clover	23 and 24	3,127	3,307	3,139	3,191
Mean		3,127	3,210	3,046	3,128
Fed:					
Fallow	17 and 18	2,959	2,796	2,724	2,826
Beans or clover	19 and 20	3,113	2,849	2,892	2,951
Mean		3,036	2,823	2,808	2,889
Mean of all		3,082	3,016	2,927	3,008

SUPERPHOSPHATE.

Fallow:					
Roots carted	13 and 14	2,938	2,753	2,786	2,826
Roots fed	9 and 10	2,976	2,702	2,947	2,875
Mean		2,957	2,728	2,867	2,851
Beans or clover:					
Roots carted	15 and 16	3,185	2,978	2,897	3,020
Roots fed	11 and 12	3,312	3,170	3,110	3,197
Mean		3,249	3,074	3,004	3,109
Mean of all		3,103	2,901	2,935	2,980
Carted:					
Fallow	13 and 14	2,938	2,753	2,786	2,826
Beans or clover	15 and 16	3,185	2,978	2,897	3,020
Mean		3,062	2,866	2,842	2,923
Fed:					
Fallow	9 and 10	2,976	2,702	2,947	2,875
Beans or clover	11 and 12	3,312	3,170	3,110	3,197
Mean		3,144	2,936	3,028	3,036
Mean of all		3,103	2,901	2,935	2,980

TABLE 90.—*Agdell field experimental rotation land, etc.*—Continued.

MIXED MANURE.

	Plats.	Samples collected in— November, 1867 (after wheat).	October, 1874 (after clover).	November, 1883, to January, 1884 (after wheat).	Mean.
		Pounds per acre.	*Pounds per acre.*	*Pounds per acre.*	*Pounds per acre.*
Fallow:					
Roots carted	5 and 6	3,010	2,887	2,918	2,938
Roots fed	1 and 2	3,197	2,940	2,986	3,041
Mean		3,104	2,914	2,952	2,990
Beans or clover:					
Roots carted	7 and 8	3,038	3,096	3,012	3,049
Roots fed	3 and 4	3,194	3,293	3,408	3,298
Mean		3,116	3,195	3,210	3,174
Mean of all		3,110	3,054	3,081	3,082
Carted:					
Fallow	5 and 6	3,010	2,887	2,918	2,938
Beans or clover	7 and 8	3,038	3,096	3,012	3,049
Mean		3,024	2,992	2,965	2,994
Fed:					
Fallow	1 and 2	3,197	2,940	2,986	3,041
Beans or clover	3 and 4	3,194	3,293	3,408	3,298
Mean		3,196	3,117	3,197	3,170
Mean of all		3,110	3,054	3,081	3,082

SUMMARY.

Unmanured		3,082	3,016	2,927	3,008
Superphosphate		3,103	2,901	2,935	2,980
Mixed manure		3,110	3,054	3,081	3,082

As far as the unmanured plats are concerned, the growth of roots was for the greater part of the time so small that it may be said that, practically speaking, there was no crop of roots either to cart or to feed.

When we come to the superphosphate plats, however, the consumption of the roots on the land has greatly affected the fertility of the soil. There being no supply of manurial nitrogen, the strain on the nitrogen contents of the soil in this rotation has been great, and the exhaustion of the soil nitrogen has necessarily been much greater on the "carted" portions of the plats than on those on which the roots have been consumed. On the whole, it will be seen that in the fallow rotation plats of the superphosphate series analysis indicates a larger proportion of nitrogen in the "fed" plats than in the "carted" plats, this being especially marked in the samples taken in 1883–84, at the end of thirty-six years, or nine rotations. This superiority in nitrogen contents accords with the greater fertility of the soil, as evidenced in its crops.

On the leguminous portions of the plats (beans or clover instead of fallow), where, as we shall see presently, there is more nitrogen to conserve, the "fed" plats show throughout a very decided superiority in nitrogen to the "carted" plats. This also accords with the relative fertility of the plats as evidenced by their crops.

In the case of the very liberally manured series ("mixed manure"), the plats on which the roots have been fed show in every case more nitrogen than those from which the roots have been carted, this being more especially the case again in the plats on which leguminous vegetation takes part in the rotation.

The data, however, to which I am more especially desirous of directing your attention are those relating to the comparison (whether on the "carted" or on the "fed" plats) of the fallow portions with those portions on which leguminous plants have taken a place in the rotation. These are best studied by the arrangement of figures to be found in the right-hand half of each of the Tables 89 and 90.

Taking first the unmanured land, it will be seen that both in 1874, in the seventh rotation, and in 1883–84, after the ninth rotation, the leguminous land was found to be decidedly richer in nitrogen than the fallow land. In five out of the six cases in which the soils were comparatively analyzed there was found on the average, in the surface soils of these unmanured leguminous plats, about 126 pounds more of nitrogen per acre than on the plats on which neither beans nor clover were grown.

On the superphosphate series there is also throughout a great advantage in favor of the leguminous plats. On the plats from which the turnips are annually carted we find that the portions on which beans or clover have been grown show on the average 194 pounds more of organic nitrogen per acre in the surface soil than do the fallow portions, while if we regard the plats which have been kept in higher condition by the consumption of the roots on the land, the superiority in the soils under the leguminous rotations, as compared with those under rotations which included a bare fallow, is represented by an average of no less than 322 pounds of nitrogen per acre.

So in the mixed manure series the advantage on the whole lies distinctly with the bean or clover land, the average excess of nitrogen found in it as compared with the fallowed portions of the plats being 111 pounds per acre where the roots are carted, and as much as 257 pounds per acre where the roots are fed.

Thus we have from these plats further interesting analytical testimony, if such were needed, to the effect of leguminous crops in increasing or maintaining the nitrogenous contents of the soil, and also analytical evidence of the effect on the soil of the alternative methods of carting or consuming the root crop.

So far we have been referring only to the organic or total nitrogen found in the soils. The soils of some of the plats, however, have been subjected to a much more complete examination as regards their contents of nitric nitrogen, which on four of the plats has been determined in twelve successive depths of 9 inches each, or to a total depth of 9 feet. In some other cases the nitric nitrogen was determined either in the surface soil or in some of the subsoils. The determinations were made in the samples taken in the winter of 1883–84, after wheat, and the results are given in the following table:

TABLE 91.—*Agdell field experimental rotation land—Soil samples collected 1883–84, after wheat*—NITROGEN *as* NITRATES (“*nitric*” *nitrogen*) *in fine dry soil.*

NITRIC NITROGEN, PARTS PER MILLION.

Depth.	Unmanured.				Superphosphate.				Mixed manure.			
	Fed.		Carted.		Fed.		Carted.		Fed.		Carted.	
	Fallow; plats 17 and 18.	Clover or beans; plats 19 and 20.	Fallow; plats 21 and 22.	Clover or beans; plats 23 and 24.	Fallow; plats 9 and 10.	Clover or beans; plats 11 and 12.	Fallow; plats 13 and 14.	Clover or beans; plats 15 and 16.	Fallow; plats 1 and 2.	Clover or beans; plats 3 and 4.	Fallow; plats 5 and 6.	Clover or beans; plats 7 and 8.
First 9 inches	......	......	1.85	......	......	......	1.32	1.44	1.35	2.41	......	......
Second 9 inches	......	......	.66	......	......	......	1.14	1.50	1.34	1.90	......	......
Third 9 inches	......	......	......	......	......	......	.42	.67	.35	.72	......	......
Fourth 9 inches	......	......	......	......	......	......	.40	.43	.45	.58	......	......
Fifth 9 inches	......	......	......	......	......	......	.19	.50	.34	.64	......	......
Sixth 9 inches	......	......	......	......	......	......	.21	.61	.24	.32	......	......
Seventh 9 inches	......	......	......	......	......	......	.46	.32	.29	.84	......	......
Eighth 9 inches	......	......	......	......	......	......	.57	.60	.34	.64	......	......
Ninth 9 inches	......	......	......	......	......	......	1.19	.67	.26	.98	......	......
Tenth 9 inches	......	......	......	......	......	......	1.07	.77	.78	.80	......	......
Eleventh 9 inches	......	......	......	......	......	......	1.85	.91	.59	.82	......	......
Twelfth 9 inches	0.93	0.29	1.25	0.65	1.59	0.99	1.11	.32	1.34	1.01	1.31	0.73

NITRIC NITROGEN, POUNDS PER ACRE.

Depth.	Unm. Fed. Fallow	Unm. Fed. Clover or beans	Unm. Carted. Fallow	Unm. Carted. Clover or beans	Superph. Fed. Fallow	Superph. Fed. Clover or beans	Superph. Carted. Fallow	Superph. Carted. Clover or beans	Mixed Fed. Fallow	Mixed Fed. Clover or beans	Mixed Carted. Fallow	Mixed Carted. Clover or beans
First 9 inches	......	......	4.71	......	......	......	3.36	3.66	3.44	6.13	......	......
Second 9 inches	......	......	1.53	......	......	......	2.64	3.48	3.11	4.41	......	......
Third 9 inches	......	......	......	......	......	......	.95	1.51	.79	1.63	......	......
Fourth 9 inches	......	......	......	......	......	......	.90	.96	1.01	1.30	......	......
Fifth 9 inches	......	......	......	......	......	......	.45	1.18	.81	1.52	......	......
Sixth 9 inches	......	......	......	......	......	......	.53	1.55	.61	.81	......	......
Seventh 9 inches	......	......	......	......	......	......	1.22	.85	.77	2.23	......	......
Eighth 9 inches	......	......	......	......	......	......	1.49	1.57	.89	1.68	......	......
Ninth 9 inches	......	......	......	......	......	......	2.97	1.67	.65	2.44	......	......
Tenth 9 inches	......	......	......	......	......	......	2.78	2.00	2.03	2.08	......	......
Eleventh 9 inches	......	......	......	......	......	......	4.81	2.36	1.53	2.13	......	......
Twelfth 9 inches	2.60	0.81	3.50	1.82	4.45	2.77	3.11	.90	3.75	2.83	3.67	2.04

SUMMARY—NITRIC NITROGEN, POUNDS PER ACRE.

Depth.	Unm. Fed. Fallow	Unm. Fed. Clover or beans	Unm. Carted. Fallow	Unm. Carted. Clover or beans	Superph. Fed. Fallow	Superph. Fed. Clover or beans	Superph. Carted. Fallow	Superph. Carted. Clover or beans	Mixed Fed. Fallow	Mixed Fed. Clover or beans	Mixed Carted. Fallow	Mixed Carted. Clover or beans
First to third 9 inches	......	......	......	......	......	......	6.95	8.65	7.34	12.17	......	......
Fourth to sixth 9 inches	......	......	......	......	......	......	1.88	3.69	2.43	3.62	......	......
Seventh to ninth 9 inches	......	......	......	......	......	......	5.68	4.09	2.31	6.35	......	......
Tenth to twelfth 9 inches	......	......	......	......	......	......	10.70	5.26	7.31	7.04	......	......
First to sixth 9 inches	......	......	......	......	......	......	8.83	12.34	9.77	15.80	......	......
Seventh to twelfth 9 inches	......	......	......	......	......	......	16.38	9.35	9.62	13.39	......	......
First and second 9 inches	......	......	......	......	......	......	6.00	7.14	6.55	10.54	......	......
Third to twelfth 9 inches	......	......	......	......	......	......	19.21	14.55	12.84	18.65	......	......
First to twelfth 9 inches	......	......	......	......	......	......	25.21	21.69	19.39	29.19	......	......

In the superphosphate series it will be seen that the plats selected for examination were respectively the fallow and leguminous portions of the plats from which the roots are annually carted, while in the mixed-manure series the plats selected were the two corresponding portions of the plat on which the roots are fed on the land.

Whether we take the first three depths (1 to 27 inches), the fourth to the sixth depths (28 to 54 inches), or the first six depths together (1 to 54 inches), we find in each pair of plats that the leguminous portions contain more nitric nitrogen than the fallow portions. This is especially the case on the more fertile plat of the mixed-manure series.

In the succeeding six depths the results are less regular, but the leguminous portion of the plat belonging to the more fertile series shows a greater quantity of nitric nitrogen than does the fallow portion.

The nitric nitrogen, it will be seen, has been determined, throughout all the plats mentioned in the table, in the twelfth depth of 9 inches, or at a depth of nearly 9 feet from the surface. At this depth the nitric nitrogen is uniformly greater on the fallow portions than on the leguminous portions of the plats, and the consistency of these figures throughout suggests that the difference is an indication of a greater loss of nitrates from the fallow portions, owing to the fact that the land has been kept one year in four without vegetation. In our discussion of the results obtained by examining the soils of Hoos field, we have seen how largely leguminous crops remove and assimilate the nitrates of the soil, as well as indirectly, by accumulation of nitrogenous root residue, augmenting their production.

As the practical agricultural bearing of these famous rotation experiments in Agdell field was very fully brought before you by Sir Henry Gilbert,[1] I need not now direct further attention to them, my present object having been merely to place before you the aforesaid soil investigations, which have so interesting a bearing in relation to the field results.

---

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 22.

Section VIII.

HUMUS AND ITS NITROGEN CONTENTS.

M. Grandeau, of Paris, some time since suggested the use of dilute alkali as a solvent for humus in soil analysis, and the process, in an extended form, has been applied to the investigation of a large number of soils in the United States by Professor Hilgard and Professor Jaffa, both for the extraction of humus and for the determination of soluble nitrogen. Papers on the subject have been published by both authors.[1]

The feature on which Professor Hilgard lays especial stress is not the actual percentage of humus or of nitrogen in the soil, but the ratio of "soluble" nitrogen to "soluble" humus. His investigation, up to the time of publishing the papers referred to, led him to the conclusion that if the "soluble" nitrogen was less than 2.5 parts per 100 parts of "soluble" humus, the conditions were probably so unfavorable to nitrification that the soil might be regarded as suffering practically from "nitrogen hungriness."

The process used is described by Professor Jaffa on page 35 of the report referred to, and is briefly as follows:

Hilgard's method.—The soil (5 grams or 10 grams) is extracted in a funnel, first with dilute hydrochloric acid, then with water to remove the acid, and lastly with dilute caustic soda in the experiment for determining soluble nitrogen or with dilute ammonia for the determination of soluble organic matter. Professor Hilgard uses a 4 per cent solution of caustic soda and a 6 to 7 per cent solution of ammonia. The soil is extracted as long as the filtrate remains colored.

The process was subsequently slightly modified at an annual convention of the Association of Official Agricultural Chemists of the United States.[2]

The process as used earlier by Professor Hilgard, without the just-mentioned modifications as to the strength of alkali, has been applied in the Rothamsted laboratory by Dr. N. H. J. Miller to the investigation of a large number of the Rothamsted soils, and also of a sample

[1] California Station Rpt. 1894–95, pp. 23, 35.

[2] The process as thus modified is described in U. S. Dept. Agr., Division of Chemistry Bul. 46, revised, p. 76.

of Manitoba soil very rich in nitrogen. The results are given in the following table:

TABLE 92.—*Percentages of soluble organic matter and soluble nitrogen in surface soils.*

Plat.	Date of sample.	In partially dried soil. Soluble in dilute ammonia. Dry matter.	In partially dried soil. Soluble in dilute ammonia. Organic matter.	In partially dried soil. Soluble in dilute ammonia. Mineral matter.	In partially dried soil. Soluble in dilute soda, nitrogen.	Nitrogen per cent in soluble organic matter.	In dry soil. Soluble organic matter.	In dry soil. Soluble nitrogen.	In dry soil. Total nitrogen.	Nitrogen per cent of total nitrogen.
Manitoba (Selkirk)	......	5.900	5.385	0.515	0.209	3.88	5.932	0.2302	0.618	37.25
Rothamsted garden soil (clover)	1857	....	....	....	....	....	....	.2423	.5876	41.24
1 (S2)	1879	4.705	3.800	.905	....	5.5	....	....	.4374	......
1	1879	....	....	....	....		....	.2185	.4298	50.83
2	1879	....	....	....	....	....	....	.2202	.4152	53.03
3	1879	....	....	....	....	....	....	.2075	.4102	50.85
1	1896	....	....	....	....	....	....	.1686	.3785	44.54
2	1896	....	....	....	....	....	....	.1785	.3772	47.32
3	1896	....	....	....	....	....	....	.1748	.3847	45.44
Rothamsted park:										
3	1886	....	....	....	....	6.373	2.710	.1727	.2604	66.32
7	1886	....	....	....	....	5.979	2.499	.1494	.2298	65.01
7 (chalk and lime)	1886	....	....	....	....	5.801	2.536	.1469	.2359	62.27
Sir J. Henry Gilbert's meadow	1879	....	....	....	....	6.242	2.201	.1374	.2057	66.80
Do	1888	....	....	....	....	6.642	2.293	.1523	.2405	66.33
Broadbalk field (wheat):										
2a	1893	1.507	1.247	.260	.081	6.49	1.282	.083	.1574	52.73
2b	1865	1.410	.940	.470	....	....	.96	....	.1882	......
2b	1893	2.147	1.740	.407	.111	6.38	1.793	.114	.2170	52.53
3	1865	1.180	.870	.310	....	....	.89	....	.1090	......
3	1881	1.135	.900	.235	....	....	.82	....	.1009	......
3	1893	1.007	.800	.207	.049	6.13	.82	.050	.0966	51.76
5	1893	1.300	.887	.413	.057	6.43	.91	.058	.0992	58.47
8	1893	.970	.850	.120	.062	7.28	.871	.064	.1178	54.33
9a	1893	.985	.815	.170	.060	7.33	.835	.062	.1153	53.77
10a	1893	1.080	.887	.193	.051	5.75	.913	.052	.1036	50.19
11	1893	1.060	.800	.260	.052	6.55	.822	.053	.1125	47.11
12	1893	.950	.739	.220	.062	8.48	.751	.064	.1152	55.56
13	1893	.930	.770	.160	.058	7.50	.793	.060	.1125	53.33
14	1893	.930	.740	.190	.060	8.08	.764	.062	.1227	50.53
19	1893	1.253	1.013	.240	.073	7.21	1.040	.075	.1329	56.43
Hoos field (barley):										
7^1	1889	1.300	1.145	.155	....	....	1.19	....	.2048	......
7^2	1889	2.340	1.840	.500	....	....	1.90	....	.2449	......
O^1	1889	1.320	.840	.480	....	....	.85	....	.1282	......

The data on which Professor Hilgard lays especial stress are those comprised under the heading "nitrogen per cent in soluble organic matter," which for the moment we may call the "Hilgard ratio." In the rich Manitoba soil this percentage is 3.88 only, or less than in any of the Rothamsted soils. The actual quantity of soluble nitrogen is high, the low ratio being caused by the very large proportion of humus extracted from this soil.

The Rothamsted soils examined include garden soil, the park land, Sir Henry Gilbert's meadow, and the permanent wheat and barley fields. The "Hilgard ratio" is (in round numbers) 5.5 for the rich garden soil, from 5.8 to 6.3 in the park soil, from 6.2 to 6.6 in the meadow soil, and from 5.75 to 8.48 in the wheat soils. The least fertile of the wheat soils, namely, plat 3, unmanured for fifty years, gives a "Hilgard ratio" of 6.13, and plat 5 (minerals without nitrogen for fifty years) gives 6.43, while the richest and most fertile plat, namely, plat 2b (dunged for fifty years) gives almost the same ratio, namely, 6.38.

It would seem, therefore, that although the ratio on which Professor Hilgard lays stress may serve as an index to initial nitrogenous fertility in soils comparatively newly brought under cultivation, it does not afford a means of differentiating between a starved and a fertile soil in the case of long-cultivated land such as we have at Rothamsted.

As regards the wheat soils, the quantity of soluble organic matter is greatest, as we should expect, on the continuously dunged plat, 2b, in which the proportion appears to have increased from 0.96 per cent to 1.793 per cent between 1865 and 1893; but it must be remembered that the 1865 sample was thirty years old when examined, and may possibly have undergone some decomposition or alteration. Next to the dunged plat comes the rape-cake plat, 19, with 1.04 per cent of soluble organic matter. In the other plats the variations lie between 0.751 per cent and 0.91 per cent.

The last column of the table expresses the soluble nitrogen as percentage of the total nitrogen of the soil, and it will be seen that the variations all lie within the range 47.11 per cent to 58.47 per cent. In fact, it may be broadly said that the soluble nitrogen all through follows pretty closely the total nitrogen, and in the case of the arable land is about one-half of it. If we take the plats that differ most widely in their treatment, we find 51.76 per cent of the total nitrogen to be soluble in dilute soda in the case of the permanently unmanured plat, No. 3, and 52.53 per cent, or almost the same proportion, in the case of the continuously dunged and richest plat, 2b. Of the chemically manured plats, plat 10a, continuously dressed with ammonium salts without minerals, shows 50.19 per cent, and plat 13, dressed with phosphates and potassium salts as well as ammonium salts, gives 53.33 per cent.

It would seem, therefore, that as far as the Broadbalk wheat field is concerned the determination of soluble nitrogen in the manner described does not give us any more information as to potential fertility than would be derived merely from the determination of the total nitrogen.

In the Rothamsted garden soil (clover plats) the proportion is also nearly 50 per cent, ranging from 41.24 per cent to 53.03 per cent, but in the park and meadow land it ranges from 62.27 per cent to 66.80 per cent, there being, therefore, a distinctly higher proportion of soda-soluble nitrogen than occurs in the arable land.

It is worth noting that in the garden clover soil as the percentage of total nitrogen diminishes the percentage of soluble nitrogen in that total also diminishes.

In the very rich Manitoba soil the proportion of soluble nitrogen is only 37 per cent of the total nitrogen.

CONCLUSION.

This concludes the records of the results of the Rothamsted soil investigations, which have been intrusted to me for presentation to you. That the duty has been but imperfectly fulfilled I am very sensible, and I have already pleaded in apology the great difficulty of dealing adequately with such abundant and suggestive material. With that apology I coupled an acknowledgment of the infinite pains spent by Sir Henry Gilbert in aiding and advising me in the preparation of these lectures, and now, in closing them, I wish once more to express my sense of his most valuable help; also I wish to tender to the many American friends and colleagues whom I have met at this gathering for the first time my cordial thanks for the most kind reception and the very patient hearing accorded to me as the representative, for the time being, of the Lawes Agricultural Trust Committee, and also to express the hope that many of the friendships begun during this my first visit to America may happily last for many years to come, and may be refreshed from time to time hereafter by personal meetings on both sides of the Atlantic.

POSTSCRIPT.

In my opening lecture it was my painful task to refer to the then recent loss which scientific agriculture had sustained by the death of Sir John Lawes. I have now the sorrow—little more than a year afterwards—to refer to the death of his life-long colleague, the news of which will have been received with heartfelt grief by his many friends in the American world of science. Sir Henry Gilbert died at Rothamsted on December 23, 1901, at the age of nearly 85 years. His association with Sir John Lawes dated from 1843, and had therefore lasted for nearly sixty years. It is unnecessary to add more in the way of memoir. His own record of his work to a recent period, presented to America by himself, and the further record embodied in the foregoing pages, will be a sufficient memorial of him to those conversant with the nature of the problems to which, in association with Sir John Lawes, he devoted his life and his boundless energy. It is pleasant to be able to add that, although his health had gradually failed during the year succeeding the loss of his old friend, he continued to the last to take a keen interest in his work, and transacted business connected with it to within thirty-six hours of the end. His death leaves a conspicuous gap in the ranks of English chemists.