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Yields of the Field Experiments 1901

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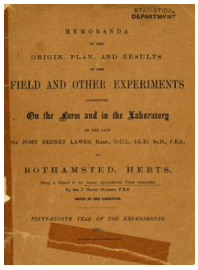

Origin, Scope, and Plan of the Rothamsted Experiments

Rothamsted Research

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ORIGIN, SCOPE, AND PLAN,

OF THE

ROTHAMSTED EXPERIMENTS.[1]

Mr. (afterwards Sir) John Bennet Lawes was the founder of the Rothamsted Experimental Station. He commenced experiments with different manuring substances, first with plants in pots, and afterwards in the field, soon after entering into possession of his hereditary property at Rothamsted[2] in 1834. The researches of De Saussure on vegetation were the chief subjects of his study to this end. Of all the experiments so made, those in which the neutral phosphate of lime, in bones, bone-ash, and apatite, was rendered soluble by means of sulphuric acid, and the mixture applied for root-crops, gave the most striking results. The results obtained on a small scale in 1837, 1838, and 1839, were such as to lead to more extensive trials in the field in 1840 and 1841, and subsequently.

In 1843, more systematic field experiments were commenced; and a barn, which had previously been partially applied to laboratory purposes, became almost exclusively devoted to agricultural investigations. The foundation of the Rothamsted Experimental Station may be said to date from that time (1843).

The Rothamsted station has from the commencement been entirely disconnected from any external organization, and has been maintained entirely at the cost of the late Sir John Lawes. It had in previous years been stated, that he had further set apart a sum of £100,000, the Laboratory, and certain areas of land, for the continuance of the investigations after his death. In February 1889, Trustees were appointed, and the necessary Trust Deed was executed; and, in accordance with the provisions of the Deed, a Committee of Management was soon afterwards appointed, and entered upon its duties.

(1) The statement of the origin, scope, and plan, of the Rothamsted Investigations, was originally drawn up in answer to a circular letter issued by a Committee appointed to arrange for the commemoration of the twenty-fifth anniversary of the establishment of the First Experimental Station in Germany (Möckern), which was held in Leipzig in September 1877. The precise form of the statement depended on the order and form of the questions to which it was an answer. It was published in German, almost in full, with the series of reports of other Experimental Stations, which was issued at the time of the Jubilee Meeting. (Die landwirthschaftlichen Versuchs-Stationen. Band xxii. 1877.) To the general statement, which is annually given in the form in which it was originally drawn up, but which is each year corrected up to date, are appended lists of the titles of all the papers already published, with full reference to the Journals in which they appeared.

(2) Rothamsted is in Hertfordshire, twenty-five miles from London, on the Midland Railway; Station, Harpenden. Postal address—Harpenden, St. Albans. Telegraphic address—Harpenden.

N.B.—It is requested that those wishing to inspect the experiments will give notice, either by letter or telegram, to Sir J. Henry Gilbert, as to the time of their intended visit.

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From June 1843, up to the time of Sir John Bennet Lawes' death in August 1900, Dr. (now Sir) J. Henry Gilbert was associated with him in the conduct of the experiments, and has had the direction of the laboratory.

In 1854–5 a new laboratory was built, by public subscription of agriculturists, and was presented to Sir John Lawes in July 1855, from which date the old barn-laboratory was abandoned, and the new one has been occupied.

The number of assistants and other helps has increased from time to time. At first only one laboratory man was employed; but very soon a chemical assistant was necessary, and next a computer and record-keeper.

For many years the staff has consisted of—

One or two, and sometimes three, chemists.

Two or three general assistants. One of these is usually employed in routine chemical work, but sometimes in more general work. The chief occupation of the general assistants is to superintend the field experiments—that is, the weighing and mixing of the manures, the measurement of the plots, the application of the manures, and the harvesting of the crops; also, the taking of samples, the preparation of them for preservation or analysis, and the determinations of dry matter, ash, &c. These assistants also keep the meteorological records, and superintend any experiments made with animals.

A botanical assistant has also occasionally been employed, with from three to six boys under him; and with him has been associated one of the permanent general assistants, who at other times undertakes the botanical work.

Two or three (and sometimes four) computers and record-keepers have been occupied in calculating and tabulating field, feeding, and laboratory results, copying, &c.

A laboratory man, and other helps, are also employed.

Besides the permanent laboratory staff, chemical assistance has frequently been engaged in London, or elsewhere. In this way, Mr. R. Richter, now of Charlottenburg (Berlin), but who was for some years in the Rothamsted Laboratory, has executed much analytical work sent from Rothamsted. He has, in fact, here and at Charlottenburg, made about 900 complete analyses of the ashes of various products, animal and vegetable, of known history.

The field experiments, and occasionally feeding experiments, also employ a considerable but a very variable number of agricultural labourers.

There is now a collection of about 50,000 bottles of samples of experimentally-grown vegetable produce, of animal products, of ashes, or of soils, besides some thousands of samples not in bottles; and, the Laboratory having become very inconveniently full, a new detached building—a "Sample House"—was erected in the autumn of 1888, comprising two large rooms for the storing of specimens, and for some processes of preparation, and also a drying room. The Laboratory, where a very large number of specimens, and the records, will still be kept, is thus relieved of the heavier, the more bulky, and the more combustible, of its former contents, and also of the risk of fire from stove-drying.

Nothing has been done at Rothamsted in the way of manure, feeding-stuff, or seed-control.

The investigations may be classed under two heads :—

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I.—FIELD EXPERIMENTS, EXPERIMENTS ON VEGETATION, ETC.

The general scope and plan of the field experiments has been:—

To grow some of the most important crops of rotation, each separately, year after year, for many years in succession on the same land, without manure, with farmyard-manure, and with a great variety of chemical manures; the same description of manure being, as a rule, applied year after year on the same plot. Experiments on an actual course of rotation, without manure, and with different manures, have also been made. In this way field experiments have been conducted for the periods, and over the areas, indicated in the following Table:—

Crops.	Duration.	Area.	Plots.
	Years.	Acres.	
Wheat (various manures)	58	11	34 (or 37) (7)
Wheat, alternated with Fallow ..	50	1	2
Wheat (varieties)	15	4–8	about 20
Barley (various manures)	50	$4\frac{1}{4}$	29
Oats (various manures)	10 (1)	$0\frac{3}{4}$	6
Beans (various manures)	32 (2)	$1\frac{1}{4}$	10
Beans (various manures)	27 (3)	1	5
Beans, alternated with Wheat	28 (4)	1	10
Clover (various manures)	29 (5)	3	18
Various Leguminous Plants	24	3 (8)	18 (8)
Turnips (various manures)	28 (6)	8	40
Sugar Beet (various manures)	5	8	41
Mangel-Wurzel (various manures) ..	26	8	41
Total Root Crops ..	59		
Potatoes (various manures)	26	2	10
Rotation (various manures)	54	3	12
Permanent Grass (various manures)	46	7	22

(1) Including 1 year Fallow.
(2) Including 1 year Wheat, and 5 years Fallow.
(3) Including 4 years Fallow. (4) Including 2 years Fallow.
(5) Clover, 12 times sown (first in 1848), 8 yielding crops, but 4 of these very small, 1 year Wheat, 5 years Barley, 12 years Fallow.
(6) Including Barley without Manure 3 years (11th, 12th, and 13th seasons).
(7) Reduced to 19 plots in 1894 and since (see plan, p. 28, also description, p. 31). (8) Reduced in 1898 to $\frac{5}{6}$ths of an acre, and to 5 plots.

Comparative experiments with different manures have also been made on other descriptions of soil, in other localities.

Samples of all the experimental crops are taken, and brought to the laboratory. Weighed portions of each are partially dried, and preserved for future reference or analysis. Duplicate weighed portions of each are dried at 100° C., the dry matter is determined, and it is then burnt to ash on platinum sheets, in cast-iron muffles. The quantities of ash are determined and recorded, and the ashes themselves are preserved for reference, or analysis.

In a large proportion of the samples the nitrogen is determined; and in some the amount existing as albuminoids, amides, and nitric acid.

In selected cases, illustrating the influence of season, manures, exhaustion, &c., complete ash-analyses have been made, numbering in all more than 800.

Also in selected cases, illustrating the influence of season and manuring, quantities of the experimentally-grown Wheat grain have been sent to the mill, and the proportion and composition of the different mill-products determined.

In the Sugar Beet, Mangel-Wurzel, and Potatoes, the sugar has in many cases been determined by polariscope, and frequently by copper also.

In the case of the experiments on the Mixed Herbage of Permanent Grass-land, besides the samples taken for the determination of the chemical composition (dry matter, ash, nitrogen,

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woody fibre, fatty matter, and composition of ash), carefully averaged samples have frequently been taken for the determination of the botanical composition. In this way, on four occasions, at intervals of five years—viz., in 1862, 1867, 1872, and 1877—a sample of the produce of each plot was taken, and submitted to careful botanical separation, and the percentage, by weight, of each species in the mixed herbage determined. Partial separations, in the case of samples from selected plots (frequently of both first and second crops), have also been made in many other years.

Investigation of Soils.

Samples of the soils of most of the experimental plots have been taken from time to time, generally to the depth of 9, 18, and 27 inches, sometimes to twice, and sometimes, for special purposes, to even four times this depth; samples being taken at two, or sometimes even at eight places, on the same plot. In this way more than 4200 individual samples have been taken; but sometimes those of corresponding depth from the different places on the same plot, have been at once mixed, so that the number for analysis has thus been reduced by about two-fifths. The individual or mixed samples are submitted to partial mechanical separation; generally some further mixtures are then made; and weighed portions (frequently several), of the individual or mixed sifted soils, are carefully preserved for analysis. In a large number of samples the loss on drying at different temperatures, and at ignition, has been determined. In most the nitrogen has been determined, in many by the soda-lime method, but in recent years the Kjeldahl method has also been used. In many the carbon, and in many the nitrogen as nitric acid, and the chlorine, have been determined. Some experiments have also been made on the comparative absorptive capacity (for water and ammonia) of the different soils and subsoils. The systematic investigation of the amount, and the condition, of the nitrogen, and of some of the more important mineral constituents, of the soils of the different plots, and from different depths, has been undertaken, and is from time to time recurred to. The results of the numerous investigations of the Rothamsted soils were last year brought together, and were, under the auspices of the Lawes Agricultural Trust Committee, made the subject of a series of lectures by Dr. Bernard Dyer, which he delivered at the Convention of the Association of American Agricultural Colleges and Experiment Stations, held at New Haven, Conn., U.S.A., in November 1900. It is hoped that the lectures, including the whole of the results in question, will be published by the United States Department of Agriculture in the course of the present year.

Rainfall and Drainage.

Almost from the commencement of the field experiments the rainfall has been measured, for more than forty-eight years in a gauge of one-thousandth of an acre area, as well as in an ordinary small funnel-gauge of 5 inches diameter. An 8-inch "Board of Trade" copper gauge has also been in use since January 1, 1881. The nitrogen, as ammonia and as nitric acid, has periodically, and for some years past monthly, been determined in the rain waters. The chlorine has been determined in a considerable series of samples; and sometimes the sulphuric acid also.

Three "drain-gauges," also each of one-thousandth of an acre area, for the determination of the quantity and composition of the water percolating respectively through 20 inches, 40 inches, and 60 inches depth of soil (with its subsoil in natural state of consolidation) were constructed in 1870. A more numerous series of smaller "drain-gauges," arranged for the investigation of the influence of different crops, and of different manures, on the amount and composition of the drainage waters, were constructed in 1874; but they proved not to be water-tight, and have therefore not been used.

Each of the differently manured plots of the permanent experimental Wheat-field having a separate pipe-drain, samples of the drainage waters have been, and are still, collected and analysed. For the purpose of collection, an open pit was, in 1866, dug at the point of junction of each individual plot-drain with the main cross-drain, and the connection broken. The collection-pits were, however, 22 yards further from the manure- and crop-line of the

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plots at one side of the field than at the other. During the spring of 1896, a brick trench, 434 feet long, and nearly 3 feet wide and deep, was constructed, at a uniform distance from the manure- and crop-line of all the plots, into which the plot-drain of each was brought; a length of cement-jointed glazed piping being substituted for the "horse-shoe and sole" drains, up to within 6 feet of the manure- and crop-line, thus equalising and lessening the distance that the unjointed drains run under unmanured and uncropped land subject to the passage downwards of surface-water. This arrangement for the better collection of the drainage water from the experimental plots has already been found to be a great improvement; and it will doubtless prove of much value in the future.

More than 25 years ago, Professor Frankland determined the nitrogen, as ammonia, as nitric acid, and as organic nitrogen, and also some other constituents, in many samples both of the rain and of the various drainage-waters collected at Rothamsted. The late Dr. Voelcker also determined the combined nitrogen, and likewise the incombustible constituents, in sixty-five samples of the drainage-waters. And Dr. W. J. Russell has determined the sulphuric acid in some of the monthly mixed samples of rain-water.

The nitrogen existing as nitric acid, sometimes that in other forms, and also some other constituents, are, and for some time past have been, determined periodically, in the Rothamsted Laboratory, in both the rain and the various drainage waters.

Amount of Water Transpired by Plants.

Commencing in 1849, experiments were made, for ten years in succession, to determine the amount of water given off by plants during their growth. In this way various plants, including representatives of the gramineous, the leguminous, and other Orders, were experimented upon. Similar experiments were also made with various evergreen and deciduous trees.

Botanical Characteristics, &c.

Having regard to the difference in the character and amount of the constituents assimilated by plants of different botanical relationships, under equal external conditions, or by the same description of plants, under varying conditions, observations have been made on the character and range of the roots of different plants, and on their relative development of stem, leaf, &c. In the case of various crops, but more especially with Wheat and Beans, samples have been taken at different stages of growth, and the composition determined, in more or less detail, sometimes of the entire plant, and sometimes of the separated parts. In a few cases, the amounts of dry matter, ash, nitrogen, &c., in the above-ground growth of a given area, at different stages of development, have been determined. The amounts of stubble of different crops have also occasionally been estimated. Experiments have also been made to ascertain approximately the acidity of the root-sap of a large number of plants representing various Natural Orders.

Experiments on the Assimilation of Free Nitrogen.

Experiments were commenced in 1857, and conducted for several years in succession, to determine whether plants assimilate free or uncombined nitrogen, and also various collateral points. Plants of the gramineous, the leguminous, and of other families, were operated upon. The late Dr. Pugh took a prominent part in this inquiry. The conclusion arrived at was that our agricultural plants do not themselves directly assimilate the free nitrogen of the air by their leaves.

In recent years, however, the question has assumed quite a new aspect. It now is—whether the free nitrogen of the atmosphere is brought into combination under the influence of micro-organisms, or other low forms, either within the soil, or in symbiosis with a higher plant, thus serving indirectly as a source of nitrogen to plants of a higher order. Considering that the results of Hellriegel and Wilfarth on this point were, if confirmed, of great significance and importance, it was decided to make experiments at Rothamsted on somewhat similar lines. Accordingly, a preliminary series was undertaken in 1888; more extended series were conducted in 1889, and in 1890; and the investigation was continued up to the commencement

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of the year 1895. Further experiments relating to certain aspects of the subject were commenced in 1898, and are still in progress. The results have shown that, when a soil growing leguminous plants is infected with appropriate organisms, there is a development of the so-called leguminous nodules on the roots of the plants, and, coincidently, increased growth and gain of nitrogen. The subject is further referred to at pp. 37 and 48 *et seq.*

II.—EXPERIMENTS ON ANIMALS, ETC.

Experiments with the animals of the farm were commenced early in 1847, and have been continued, at intervals, nearly up to the present time.

The following points have been investigated:—

1. The amount of food, and of its several constituents, consumed in relation to a given live-weight of animal within a given time.

2. The amount of food, and of its several constituents, consumed to produce a given amount of increase in live-weight.

3. The proportion, and relative development, of the different organs or parts of different animals.

4. The proximate and ultimate composition of the animals in different conditions as to age and fatness, and the probable composition of their increase in live-weight during the fattening process.

5. The composition of the solid and liquid excreta (the manure) in relation to that of the food consumed.

6. The loss or expenditure of constituents by respiration and the cutaneous exhalations—that is, in the mere sustenance of the living meat-and-manure-making machine.

7. The yield of milk in relation to the food consumed to produce it; and the influence of different descriptions of food, on the quantity, and on the composition, of the milk.

The general plan of experimenting was as follows:—

To provide data as to the amount of food, or its several constituents, consumed in relation to a given live-weight of animal within a given time, and to produce a given amount of increase in live-weight, several hundred animals—oxen, sheep, and pigs—have been experimented upon. Selected lots of animals were supplied, for many weeks, or for months consecutively, with weighed quantities of foods, selected and allotted according to the special point under inquiry. The composition of the foods was determined by analysis. The weights of the animals were taken at the commencement, at intervals during the progress, and at the conclusion of the experiment.

The amount, and relative development, of the different organs and parts were determined in 2 calves, 2 heifers, 14 bullocks, 1 lamb, 249 sheep, and 59 pigs.

The percentages of water, mineral matter, fat, and nitrogenous substance, were determined in certain separated parts, and in the entire bodies, of ten animals—namely, one calf, two oxen, one lamb, four sheep, and two pigs. Complete analyses of the ashes, respectively, of the entire carcasses, of the mixed internal and other "offal" parts, and of the entire bodies, of each of these ten animals, have also been made.

From the data provided, as just described, as to the chemical composition of the different descriptions of animal, in different conditions as to age and fatness, the composition of the increase whilst fattening, and the relation of the constituents stored up in increase to those consumed in food, have been estimated.

To ascertain the composition of the manure in relation to that of the food consumed, oxen, sheep, and pigs, have been experimented upon.

In the case of oxen, the food and litter (sometimes with an acid absorbent), were weighed, sampled, and analysed; the animals were fed in boxes, for periods of from five to nine weeks, and the total dung produced was well mixed, weighed, sampled, and analysed. The constituents

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determined in the food and litter on the one hand, and in the dung on the other, were dry matter, ash, and nitrogen.

In the case of sheep no litter was used; the animals were kept in lots of five, on rafters, through which (but with some little loss) the solid and liquid excreta passed on to a sheet-zinc flooring at such an incline that the liquid drained off at once into carboys containing acid, and the solid matter was removed two or three times daily, and also mixed with acid. The constituents determined in the food and manure were dry matter, mineral matter, sometimes woody-fibre, and nitrogen.

In the case of pigs, individual male animals were experimented upon, each for periods of three, five, or ten days only. Each animal was kept in a frame, preventing it from turning round, and having a zinc bottom, with an outlet for the liquid to run into a bottle, and it was watched night and day, and the voidings carefully collected as soon as passed, which could easily be done, as the animal never passed either fæces or urine without getting up, and in getting up he rang a bell, and so attracted the notice of the attendant. The constituents determined were, in the food and fæces, dry matter, ash, and nitrogen, and in the urine, dry matter, ash, nitrogen, and urea.

The loss or expenditure of constituents, by respiration and the cutaneous exhalations has not been determined directly, that is, by means of a respiration-apparatus, but only by difference, that is, by calculation, founded on the amounts of dry matter, ash, and nitrogen in the food, and in the (increase) fæces, and urine.

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

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

Supplementary Investigations.

In conjunction with the late Professor Way, an extensive investigation was undertaken on the application of town sewage to different crops, but especially to grass. The amount, and the composition, of both the sewage and the produce grown were determined; and, in selected cases, the composition of the land drainage-water was also determined. Comparative experiments were also made on the feeding qualities of the differently grown produce; the amount of increase yielded by oxen, and the amount and composition of the milk yielded by cows, being determined. In this inquiry part of the analytical work was performed at Rothamsted, but most of it by Professor Way in London.

The chemistry of the malting process, the loss of food constituents during its progress, and the comparative feeding value of barley and malt, have been investigated.

Experiments were commenced in 1884, and continued for several years, to determine the changes and losses which food-crops undergo in the process of ensilaging. Experiments have also been made to determine the comparative value as food—of red-clover-silage as against red-clover-hay-chaff and swedes, when given (with other foods), to fattening oxen; of red-clover-silage, and meadow-grass-silage, as against mangels, when given (with other foods) to milking cows; of silaged green oats, against oats (grain and straw) allowed to ripen, given (with other foods) to fattening oxen; and of meadow-grass-silage, as against corresponding meadow-grass-hay, given (with other foods) to fattening oxen.

A mixed crop of beans, peas, tares, and oats, was silaged in 1886, 1887, and in 1888, and the changes and losses determined by weight and analysis, but the silage was not fed experimentally. A similar mixed crop was sown in June 1889; but it failed, and was ploughed up.

Although many of the results of the investigations above enumerated have already been published, a large proportion as yet remains unpublished.