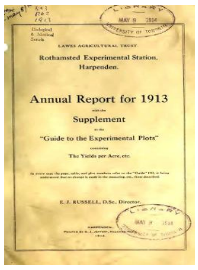
Annual Report for 1913 With the Supplements to the Guide to the Experimental Plots Containing the Yields per Acre, Etc.



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Rothamsted Report for the Year 1913

Rothamsted Research

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ANNUAL REPORT

FOR THE YEAR 1913

THE distinguishing features of 1913 were its sunless, rainy spring and its dry, sunless summer. The temperature was, on the whole, somewhat above the average excepting in July, when it was distinctly lower. There were many more wet days in January, March and April than usual, and at the end of the latter month we had had no less than 10 inches of rain instead of the normal 7·9. June, July, August and September were, however, very dry; October and November had the average rain fall, but December was considerably drier than usual. For the whole year the rainfall was 24·72 inches, this being 3·62 inches or 12·8 per cent. below the average. This deficit was characteristic of much of the Eastern part of England, although, as Dr. Mill has pointed out, there was approximately an equal excess over much of the West. The number of hours of bright sunshine was 1337, being 255 less than the average. The deficit arose during the four months, January to April, and the three months July to September, particularly during July when we had 93 hours only instead of the average 218.

From the farmer's standpoint the October of 1912 had been favourable but November had been wet, so that work was delayed and a smaller area of winter corn was sown than was intended. December was fine, however, and the wheat and winter oats made a good start. The land was very wet at the end of December, but on the whole, the conditions were good till the middle of March, so that all the spring corn went in well. Then the persistent wetness and the increasing excess of rainfall began to tell, and work on the potato land was brought to a standstill, and instead of getting in the crop early in April, we had to wait to the third week in May. The sowing of mangolds was similarly delayed and it was May 30th before Barnfield was sown. This field, which has carried root crops with only a three-year break since 1843, is somewhat difficult to manage in spring: it tends to become suddenly hard on top while underneath it is still too spongy to carry the horses. In consequence, the season for getting in the seed is easily missed. Even the dunged plots show this behaviour to some extent, though not so markedly as those receiving no organic manure. The farm mangolds could not be sown till June 9th and did very badly. The swedes on Little Hoos field went in well and came up well, but a large proportion of the plant died because no rain fell: more seed was sown on July 16th but the crop failed. A fair crop of hay was secured: it was given four clear days to make and went into the stack well, showing no tendency to become heated like a good deal of hay in the district that had been hurried in too quickly.

The harvest came early and the weather was exceedingly good. Winter oats and wheat yielded well, spring oats were rather below, but barley was above the average.

In the experiment plots, the outstanding feature of the year was the extraordinarily large crop of barley in Hoos Field. Right from the outset the plants grew remarkably well and they went through to the end without a check. The plots without potash tended to become laid: those supplied with nitrogen tended to form their ears more rapidly than those which received no nitrogen: while the plots receiving phosphates began as usual to ripen earlier than the others. In all cases the crops were very uniform over the whole plot, and the irregularities which showed in 1911 on plot 2A vanished entirely. Several of the plots yielded over 60 bushels of grain, 30 cwt. of straw and 7,000 lb. of total produce per acre: to find any parallel we have to go back nearly 60 years. The season was of course very favourable for barley: the spring being moist and the summer cool and dry. But there was another circumstance which appears to have contributed to the high yield. For 60 years in succession, barley crops have been grown continuously in Hoos Field without any break, but recently weeds had accumulated to such an extent that after the harvest of 1911 it was decided to fallow the field for a year, cultivating thoroughly to keep the land free from all growth during the season, and, of course, withholding all manure. The fallow ended in March, 1913.

There can be little doubt that the fallow played a considerable part in bringing about the high yield. It is difficult to account for the result on our present views as to the effects of fallowing: something more seems to be involved than the accumulation of nitrate over the winter. Laboratory work, discussed later on, indicates the existence of another factor: an apparent effect of a growing crop on bacterial decompositions in the soil which is not exerted during the fallow period. The important problems thus opened up are under further investigation.

Another very important problem is raised by these results. The yield—60 bushels of grain and 30 cwt. of straw—is extraordinarily high for us, and has been obtained only three times before, *viz.*, 1854, 1857 and, in Agdell Field only, in 1861. It seems to represent the utmost our soil can do. There is remarkably little variation between the best plots this year, seven of them varying only within 4 bushels, *viz.*, from 60 to 64, and the variation does not become much wider if one includes the three early years and the Rotation experiments as well as the continuous crop. This result is readily explained on physiological grounds: of the various plant requirements, all must be satisfied, or growth will not continue. If any one is withheld, it sets a limit beyond which crop growth will not take place. Lack of food, water, temperature may all constitute limiting factors, any of which would prevent the crop from rising indefinitely. The fact that our crop has not yet been pushed beyond 64 bushels during the 60 years of experiment shows that some limiting factor is at work which is not overcome by any of the manurial combinations or cultivation methods we use.

The limit may be set by the sheer inability of the plant to grow any larger, in which case, the plant breeder could come to the rescue by producing more vigorously growing varieties. But this was not the case here. Sixty-four bushels of barley is by no means a record crop on good barley soils, and probably many farmers have obtained more. The limit in our case seems to be set by the soil type; ours is not a good barley soil, *i.e.*, it is not perfectly adapted to barley, and no mere addition of food stuffs will make it so.

The barley on the Agdell Rotation Field did not yield anything like as heavily as on the Hoos continuous plots, the highest crop being 33 bushels of grain, 15 cwt. of straw, and 3,500 lb. of total produce; these figures are far short of what has been obtained from the same plots in certain previous years. The difference is presumably the result of the fallow in Hoos Field, for all other conditions were the same in both cases: this view is strengthened by the fact that the unmanured plot on Agdell (which had virtually been fallowed during the preceding year, the turnip crop having failed) gave 18·5 bushels of grain and 8 cwt. of straw, nearly the same yield as the unmanured Hoos Field plot, 21 bushels of grain and 10 cwt. of straw. Only where the turnip crop had grown in 1912 were the yields markedly less than on Hoos Field.

An interesting result was obtained on the two unmanured plots in Agdell Field. On one of these the rotation is dead fallow, wheat, swedes, barley; on the other it is clover, wheat, swedes, barley. On the manured plots the clover brings about an increase in the wheat, but on the unmanured plot it usually exerts a depressing effect, both on the wheat and the barley. This year, however, the result was different; an increased crop was obtained on the unmanured barley plot as well as on the manured plots as a result of growing clover. The method of getting in the clover is to sow it broadcast among the barley as soon as the barley is up: in some way, the barley this year has benefited from the clover sown along with it.

The wheat on the Broadbalk plots gave much better yields than last year in consequence of there being less *Alopecurus agrestis*. The plots are still far from being clean, however, and only the yields of the lower cleaner half of the field are given in the Table. The variety grown is the Square Head's Master, which is well adapted to our conditions. At a width of 7¾ inches apart 33 rows were sown per plot:* during the period 1906--1912 the rows had been set 12 inches apart to facilitate hand hoeing: there were then 19 to 20 rows per plot in alternate years. As in the case of the barley, nitrogenous manures were found to hasten the formation of ear, plots receiving such manures being distinctly earlier than the rest in heading out. None of the yields were large: 28 bushels was the highest: this was only secured on the most heavily manured plot. These yields are below the average on Broadbalk. On the surrounding fields 36 bushels were obtained, but even this is not exceptionally high: we have twice on Broadbalk—in 1863 and 1864—had as much as 50 bushels; indeed, in 1863 we got 56 bushels of grain and 10,000 lb. total produce. On the Agdell Rotation Fields, however, the crops have never been as large. These results are wholly exceptional, and represent the combined effect of high manuring, good cultivation and an unusually good season. In normal years our most intense scheme of manuring yields only 40 to 45 bushels. Again the soil type seems to be the limiting factor, and the lesson may be drawn that the best cultivation and manuring is ineffective to push yields up beyond a certain limit set by the season and the soil type. One might try to push this limit higher and this is being done, but a no less useful line of experiment is to try and secure these same yields at lower cost.

*One afterwards had to be hoed up, leaving 32 per plot.

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THE LABORATORY AND POT CULTURE HOUSE.

The fundamental problem before the Rothamsted workers is to study the mutual relationships of the soil and the plant. For convenience of working the problem is divided into two parts: the investigation of the factors that make for greater and more vigorous growth on the part of the plant, and the study of the factors that bring about changes in the plant, particularly those associated with "quality."

At least six soil factors are now known to be concerned in plant growth: a proper supply of plant food; of water; of air for the roots; sufficient temperature; adequate root room; and the absence of harmful and injurious factors. In order to limit the problem, the work is at present confined to one of these, which, however, is often the most important in British agriculture; the supply of nitrogenous plant food. Our researches are directed to the elucidation of the chemical reactions involved in the production of nitrates in the soil, the agents bringing about the changes, and the influence on the whole process of soil and plant conditions.

It has long been known that the complex nitrogen compounds contained in farmyard manure, crop residues, etc., speedily change to nitrates in the soil. The intermediate steps are unknown, but a beginning has been made this year by Mr. Horton who is investigating the nature of the organic substances present in the soil. The work is necessarily slow and difficult, but until it is done a satisfactory solution of the problem will not be possible.

The complete system of crop and soil sampling adopted at Rothamsted enables us to make up balance sheets showing what becomes of the transformed nitrogen compounds. These prove that the nitrification process is not complete; a portion of the added nitrogen compound does not appear as nitrate, and some of it indeed cannot be traced at all. The last balance sheet was made up in 1894; but the plots are now being re-surveyed so as to bring it up to date and to show the relative efficiency of the various manurial schemes in use at Rothamsted. It is already evident, however, that certain methods and especially those involving the use of much farmyard manure, are wasteful of nitrogen, and on some of the plots less than 50 per cent. of the added nitrogen is recovered in the crop; but it is not known how the waste occurs or whether it is an inevitable accompanyment of high farming.

The assumption has been made that in these cases an evolution of gaseous nitrogen takes place, and this is of considerable scientific interest because no biochemical process is known that would liberate gaseous nitrogen under the conditions. But the economic interest is much greater. Nitrogenous manures are by far the most expensive, while stable or yard manure constantly tends to become dearer to make and harder to buy. In modern agricultural conditions it is essential to reduce waste and to get the greatest possible return from the manures applied—indeed, the unsuccessful farmer often differs from the successful man only in allowing to go unchecked a series of wastages, each in itself small. A careful study has therefore been begun to trace the missing nitrogen, to find out how it gets lost and whether there is any means of saving it. Mr. Appleyard is conducting experiments to see if gaseous nitrogen is given off from the soil, but has failed to find any considerable evolution, and it soon became clear that the reaction, if it takes place at all, goes on too slowly to be studied in a limited time in the laboratory.

The way round a difficulty of this sort is to seek out and study carefully an exaggerated case as nearly as possible parallel to the one in hand, and we had an obvious instance in a manure heap, where marked losses of nitrogen take place from its compounds. A manure heap, however, is an extraordinarily complex problem to attack and required far more time than we could give it. Fortunately, the Hon. Rupert Guinness came forward and enabled us to secure the services of Mr. E. H. Richards, formerly of the Sewage Commission, who now devotes himself entirely to this question. We are now, therefore, steadily developing our attack: while Messrs. Horton and Appleyard are studying the chemical processes in the soil, Mr. Richards is investigating the much more intense processes in the manure heap. Apart from the valuable light this last investigation may be expected to throw on the soil work, it is of great intrinsic importance by reason of its general bearing on the nitrogen losses from the farm.

The agents bringing about the production of nitrate, the loss of nitrogen, and apparently other reactions in the soil, are bacteria, and these are being studied in the James Mason Laboratory by Dr. Hutchinson and Mr. MacLennan. Hitherto they have been dealt with in groups only, but it has now become necessary to make a closer study of the various types, and about a hundred have accordingly been isolated and grown in pure culture.

The stock of soil bacteria appears to be remarkably varied; Mr. Buddin finds some which can develope in presence of strong organic poisons, such as phenol, cresol, hydroquinone, etc., and, indeed, apparently feed on these substances.

The conditions under which soil bacteria work have for some years been under investigation here, and in last year's Report reference was made to experiments showing that the bacteria are not the only active organisms in the soil, but that other and larger organisms are present which are inimical to them and keep their numbers down. Provisionally these organisms were identified with soil protozoa, and a survey of the soil fauna was begun to ascertain if protozoa were present in our soil, and, if so, whether they acted detrimentally to bacteria. Various forms were isolated from hay infusions inoculated with soil, but there was nothing to show whether they occurred in the soil in active forms or as cysts. Fortunately, Mr. Martin devised a method by which some of the protozoa can be extracted from the soil in the form in which they actually exist, and he and Mr. Lewin have shown that numbers of amoebae and of flagellates are in the active form and some at least feed on bacteria in the soil. The amoebae are at present under investigation, and prove to be new forms of considerable interest.

When soil is treated with mild antiseptics, gentle heat, or in other ways inimical to life, it is found that the soil bacteria, after a preliminary depression finally multiply more rapidly than before, and the harmful factor is put out of action. Dr. Hutchinson and Mr. MacLennan have shown that quicklime behaves like other antiseptics and causes first a depression and then a great increase in bacterial numbers, but a permanent depression in soil protozoa. The rate of ammonia production also shows the usual increase. Thus quicklime owes part of its effect to its sterilising action. This discovery throws important light on the behaviour of lime in soil and clears up much that has long been obscure. Other effects of lime on the soil of a chemical and physical nature were observed and investigated.

The usual demonstrations have been continued showing the improvement in productiveness brought about by partial sterilisation. Several large scale trials have been made in commercial glasshouses. The new Experiment Station in Lea Valley, now in course of formation, will in future take over much of this demonstration work. The laboratory work has been continued in conjunction with Mr. Buddin, who has been investigating the effect of certain typical organic antiseptics with a view to devising some general schemes of classification of substances suitable for practical application.

An investigation by Dr. Hutchinson and Mr. Goodey of the samples of soil collected from our plots at various periods and stored in dry condition has further illustrated the close parallelism established in earlier papers between the soil protozoa and the factor detrimental to bacteria. Samples collected and bottled in 1874 behaved normally on moistening—the bacteria developed, but not to any very great extent—amoebae and flagellates were found; on partial sterilisation the protozoa were killed and the bacterial numbers rose in the usual way. Samples of soil collected and bottled in 1846 and dried in 1880, however, behaved like soil already partially sterilised: on moistening, the bacterial numbers rose considerably, no protozoa were found, and no further change was produced by partial sterilisation. Thus long storage in dry condition causes the soil to lose the factor detrimental to bacteria, and it also loses its protozoa.

Besides the detrimental organisms already referred to, another factor influencing the soil decompositions has been revealed this year. Determinations of the nitrate content of our arable soils have shown that there is always less accumulation of nitrate on our cropped than on our fallow plots, even after allowing for the nitrate taken up by the plant. Examination of the data obtained here and elsewhere indicates that the growing crop in some way interferes with the process of ammonia and nitrate formation. It does not appear that the effect is merely accidental and due to some climatic factor, for Lyttleton Lyon has already obtained a similar result at Ithaca. Field experiments alone are not sufficient to solve the problem; a proper series of pot experiments is required. There are, however, several important consequences of such an interaction between the growing plant and the soil bacteria, should it be proved to exist. If the growing crop interferes with the process of ammonia and nitrate formation it is obvious that one crop may be expected adversely to affect another. Mr. Pickering's grass growing experiments afford evidence that such an interference does take place: there is, moreover, a strong opinion to this effect among practical men and the American Bureau of Soils has accepted it, and put forward a hypothesis in explanation, one, however, which we were unable to confirm at Rothamsted.

Dr. Hutchinson's experiments suggest that the Pickering effect is only produced in presence of soil bacteria, thus affording further evidence of an interaction between the growing plant and the decomposition processes. Experiments on the effect of weeds on crops and of cross cropping were started last year in conjunction with Dr. Brenchley to enable the facts to be determined more completely, and these are still going on.

A further consequence of such an interference between the plant and the soil bacteria is interesting in the study of plant nutrition. It has been commonly supposed that the plant must in natural conditions get most or all of its nitrogen as nitrate because the activities of the nitrifying organisms leave it no option, and the argument was justified so long as it could be supposed that nitrification went on independently of the growing plant. But if it turns out that the plant interferes with the production of nitrate and ammonia in soil then the necessity for the supposition disappears and it may equally be possible for the nitrogen to be taken in other forms.

A beginning has also been made this year with a systematic investigation of the soil as a medium for biological activity. This has involved a study of the constitution of the soil, and already three distinct lines of work are bringing out the biological importance of the soil colloids. Mr. Prescott has been engaged in working out the effect of dilute acids on the soil, and Mr. B. A. Keen has been determining the rate of evaporation of water from the soil, while Mr. Appleyard has been studying the gases absorbed by the soil and given up only in a vacuum. The experiments are not sufficiently advanced to justify discussion in this Report, but they promise to throw light on the constitution of the soil.

The composition of the soil atmosphere at a depth of 6 inches below the surface has been determined periodically during the year by Mr. Appleyard, and it has been shown to approximate very closely to that of ordinary air, so that organisms growing in the surface soil will find an atmosphere with practically normal oxygen content.

The second great division of the Rothamsted work—the investigation of the plant—is still in its opening stages, although marked advances have been made during the year. Dr. Brenchley has closed her work on the effect of inorganic poisons on plant growth and has prepared a monograph in which her own and other experiments are set out and the results discussed. The results are definitely against the hypothesis that all such poisons act as stimuli when applied in small quantities. Increased yields that require further examination were, however, obtained in some instances with boric acid and with manganese salts. Dr. Brenchley is now turning to the effect of certain organic substances on plant growth and will also test systematically the substances isolated from the soil by the soil chemists.

An interesting investigation has been begun by Miss Adam into the anatomical structure of certain of the grasses on the Park grass plots. It has been observed that, where potash manures are withheld, the grasses do not stand up well but tend to become "laid." Microscopic examination is being made to see whether this is accompanied by any modification in the anatomical structure.

The chemical side of the work has progressed steadily. The usual methods of analysing crops are based on old investigations made before the advent of modern organic chemistry. Pharmacologists have already adopted newer methods and we are now doing so for farm crops. During the past two years Messrs. Davis and Daish, assisted by Mr. Sawyer, have worked out a satisfactory method, of which details are given below, for estimating cane sugar, dextrose, laevulose, and maltose in plants. A further method is now being elaborated for determining the amount of starch; this is based on the fact that Taka diastase hydrolyses starch *completely* to maltose and dextrose, no dextrin being formed.

The following papers have been published during the year:—

I. "*The Weeds of Arable Land.*" III. WINIFRED E. BRENCHLEY. Annals of Botany, 1913. **27**, 141—266.

In previous seasons the investigation had been confined to sedentary soils; this year (1912), however, the records were taken on the drift soils of Norfolk. The general results, however, are closely in agreement with those obtained before, but the Norfolk weed flora agrees more closely with that of Bedfordshire than with that of the West Country. As before, the association between weeds and soil is sometimes general, sometimes only local, but the following weeds were characteristic of the soils examined this year:—

CLAY & HEAVY LOAM.	LOAMS.
Alopecurus myosuroides	Anthemis Cotula
Geranium dissectum	Bellis perennis
Heracleum Sphondylium	Brassica alba
Linaria Elatine	Chrysanthemum leucanthemum
Potentilla reptans	Euphorbia Peplus
Ranunculus arvensis	Lolium perenne
Stachys palustris	Lychnis dioica
	Papaver Argemone

SAND & SANDY LOAMS.	SANDS.
Chrysanthemum segetum	Bromus mollis
Rumex Acetosella	Echium vulgare
Scleranthus annuus	Erophila verna
Spergula arvensis	Lycopsis arvensis
	Myosotis collina

CHALK.

Artemisia vulgaris	Euphorbia Helioscopia
Cichorium Intybus	Linaria vulgaris
Crepis virens	

A relationship was found between the weed flora and the crop dependent on the purity of the crop seed, the habit of growth of the crop, and the character of the cultivation given.

II. "*A Study of the Methods of Estimation of Carbohydrates, especially in Plant Extracts.*" W. A. DAVIS & A. J. DAISH. Journal of Agricultural Science, 1913. **45**, 437—468.

A careful study has been made of the various methods by which the sugars can be determined in crops and those most suitable have been embodied in a scheme which has been found to work satisfactorily.

The plant material is extracted in a large metal Soxhlet extractor for 18 hours. The extract is then evaporated *in vacuo* (700 to 740 mm.) to a small volume and made up to a definite volume, *e.g.* 500 c.c. Of this 2 portions of 20 c.c. each are evaporated to dryness and dried *in vacuo* for 18 hours at 100°C. This gives the total dry matter in the extract. 440 c.c. are treated with the requisite volume of basic lead acetate solution, filtered under pressure on a Buchner funnel, washed and made up to a known volume, 2 litres. This is called Solution A.

300 c.c. of solution A are deleaded by means of solid $Na_2 CO_3$ and made up to 500 c.c. This is called Solution B.

(1) 25 c.c. of B are used for *direct reduction* and *polarised* ; * the reduction is due to dextrose, laevulose, maltose, pentoses.

(2) FOR CANE SUGAR. Invert 50 c.c. of B :

(*a*) By invertase. Make neutral to methyl orange by a few drops of concentrated sulphuric acid, and add 1—2 c.c. autolysed yeast and two or three drops of toluene and leave 24 hours at 38—40°C. After this period, add 5 to 10 c.c. alumina cream, filter and wash to 100 c.c. Take the reducing power of 50 c.c. (=25 c.c. B) and polarise.

(*b*) By 10 per cent. citric acid. Make faintly acid to methyl orange by a few drops of concentrated sulphuric acid and add a weighed quantity of citric acid crystals so as to have 10 per cent. of the crystalline acid ($C_6H_8O_7 + H_2O$) present. Boil 10 minutes, cool, neutralise (to phenolphthalein) with sodium hydroxide, make to 100 c.c. and determine reducing power of 50 c.c. (=25 c.c. B) ; polarise.

CANE SUGAR is calculated from the increase of reducing power or change of rotation caused by inversion. The values obtained by the two methods *a* and *b* should agree closely.

(3) FOR MALTOSE. Another 300 c.c. of Solution A is deleaded by means of hydrogen sulphide and filtered, the precipitated sulphide being washed until the total volume of filtrate and washings is about 450 c.c. Air is then sucked through this for about 1½ hours to expel hydrogen sulphide, a very little ferric hydroxide is added to remove the last traces of the latter, and the solution is made to 500 c.c. It is filtered and

50 c.c. fermented (*a*) with S. marxianus
,, ,, (*b*) ,, S. anomalus
,, ,, (*c*) ,, S. exiguus

and two lots *d* and *e* of 50 c.c. are fermented with baker's yeast. It is generally necessary in order to ensure good growth of the yeast to reduce the acidity by adding 2 to 5 c.c. of N-sodium carbonate to the 50 c.c. to be fermented ; 5 c.c. of sterilised yeast water is also added, the mixture is sterilised in the usual way and inoculated in the inoculating chamber with the pure culture of yeast. It is then stoppered with cotton wool and the yeast allowed to incubate for 21 to 28 days at 25°.

* The polarisation of these dilute solutions is usually small and it is therefore necessary to take the reading with a long tube (at least 200 mm. in length) with an instrument reading accurately to $\frac{1}{100}$, the temperature being maintained constant at 20° C within $\frac{1}{10}$°. It is an easy matter, using a Lowry thermo-regulator and circulating the water by means of a small pump, to keep the temperature constant to $\frac{1}{100}$ but differences of temperature less than $\frac{1}{10}$° hardly make a perceptible difference in the readings with such dilute solutions as these.

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After completion of fermentation 5 c.c. alumina cream is added, the solution made to 100 c.c. at 15°, filtered, and 50 c.c. used for reduction. The *difference* between the *average* reduction with *a*, *b*, *c* and the average of *d* and *e* gives the reduction due to *maltose*.

(4) PENTOSES. These are approximately determined in 50 c.c. of A, by distilling with hydrochloric acid according to the A.O.A.C. method weighing as phloroglucide.

(5) When the reduction due to pentose and maltose has been allowed for in 1, the remaining direct reduction is due to dextrose and laevulose; the actual proportions of these two sugars are calculated from the reducing power combined with the corrected rotation as suggested by Brown and Morris in the 1893 paper.

III. "*A Simple Laboratory Apparatus for the Continuous Evaporation of Large Volumes of Liquid in Vacuo.*" W. A. DAVIS. Journal of Agricultural Science, 1913. **5**, 434—436.

A description of a simple apparatus used in the above analytical process.

IV. "*The Soil Solution and the Mineral Constituents of the Soil.*" A. D. HALL, WINIFRED E. BRENCHLEY and LILIAN M. UNDERWOOD. Philosophical Transactions of the Royal Society, 1913. **204**, 179—200.

Solutions were made by extracting the soils from certain of the Rothamsted plots on which wheat and barley had been grown for 60 years and upwards. Wheat and barley were grown in these solutions, which were renewed fortnightly. The comparative growth in the solutions was closely parallel to the growth of the crop on the plots in the field and corresponded to the composition of the solutions. The composition of the solutions as regards phosphoric acid and potash corresponded to the past manurial treatment of the soils and to the amount of phosphoric acid and potash they now show on analysis. Growth in the soil solutions agreed with the growth in artificial culture solutions containing equivalent amounts of phosphoric acid and potash. Growth in the soil solutions from imperfectly manured plots was brought up to the level of that in the solutions from completely manured plots on making up their deficiencies in phosphoric acid and potash by the addition of suitable salts. The phosphoric acid and potash content of the soil solutions was of the same order as the phosphoric acid and potash content of the natural drainage water from the same plots.

Wheat grew as well as barley in the solutions of the wheat soils and *vice versa*. In similar sets of solutions from the same soils the growth of buckwheat, white lupins and sunflowers corresponded with that of wheat and barley. Boiling effected no alteration in the nutritive value of the soil solutions.

In nutritive solutions of various degrees of dilution the growth of plants varied directly, but not proportionally, with the concentration of the solution, though the total plant food present in the solution was in excess of the requirements of the plant. When the nutrient solution was diffused as a film over sand or soil particles, as in nature, there was no retardation of growth due to the slowness of

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the diffusion of the nutrients to the points in the liquid film which had been exhausted by contact with the roots. Growth in such nutrient solutions forming a film over sand particles was much superior to the growth in a water culture of equal concentration, but the growth in the water culture was similarly increased if a continuous current of air was kept passing through it.

From these data it is concluded :—

(1) The composition of the natural soil solution as regards phosphoric acid and potash is not constant, but varies significantly in accord with the composition of the soil and its past history.

(2) Within wide limits the rate of growth of a plant varies with the concentration of the nutritive solution, irrespective of the total amount of plant food available.

(3) When other conditions, such as the supply of nitrogen, water, and air are equal, the growth of the crop will be determined by the concentration of the soil solution in phosphoric acid and potash, which, in its turn, is determined by the amount of these substances in the soil, their state of combination, and the fertiliser supplied.

(4) On normal cultivated soils the growth of crops like wheat and barley, even when repeated for 60 years in succession, does not leave behind in the soil specific toxic substances which have an injurious effect upon the growth of the same or other plants in the soil.

The net result of these investigations is to restore the earlier theory of the direct nutrition of the plant by fertilisers. The composition of the soil solution which determines the growth of the plant is dependent upon the amount and the mode of combination of the phosphoric acid and potash in the soil, both of which are affected by the fertiliser supply, though to what extent is not yet determinable.

V. "*The Effect of Partial Sterilisation of Soil on the Production of Plant Food.* Part II. *The Limitation of Bacteria Numbers in Normal Soils and Its Consequence.*" E. J. Russell and H. B. Hutchinson. Journal of Agricultural Science, 1913. **5**, 152—221.

The conclusions reached in the previous paper have been confirmed and extended. Fresh evidence is adduced that bacteria are not the only inhabitants of the soil, but that another group of organisms occurs, detrimental to bacteria, multiplying more slowly under soil conditions and possessing lower power of resistance to heat and to antiseptics.

In consequence of the presence of these detrimental organisms, the number of bacteria present in the soil at any time is not a simple function of the temperature, moisture content and other conditions of the soil. It may, indeed, show no sort of connection with them ; thus rise of temperature is found to be ineffective in increasing the bacteria in the soil ; increase in moisture content has also proved to be without action. The number of bacteria depends on the difference in activity of the bacteria and the detrimental organisms.

But when soil has been partially sterilised the detrimental organisms are killed and the bacteria alone are left. It is then found that increase in temperature (up to a certain point) favours bacterial multiplication and causes the numbers to rise. Variations in moisture content also produce the normal results on partially sterilised, but not on untreated, soils.

The detrimental organisms are killed by any antiseptic vapour, or by heating the soil for three hours to 55°-60°C: they suffer considerably when the soil is maintained at lower temperatures (40°C) for a sufficient length of time. Cooling to low temperatures also depresses them, although it fails to kill them.

The completeness of the process can be accurately gauged by the extent to which the bacteria suffer. Whenever the treatment is sufficiently drastic to kill the nitrifying organisms and to reduce considerably the numbers of the other bacteria (as shown by the counts on gelatine plates) it also kills the detrimental organisms. If the soil conditions are now made normal, and the antiseptic is completely removed, rapid increase is observed in the bacterial numbers and the rate of production of ammonia. A temporary or partial suppression of the factor is, however, possible without extermination of the nitrifying organisms.

Once the detrimental organisms are killed, the only way of introducing them again is to add some of the untreated soil. But the extent of the transmission is apt to be erratic, being sometimes more and sometimes less complete than at others; occasionally the infection fails altogether. We have not yet learned the precise conditions governing the transmission.

Provisionally we identify the detrimental organisms with the active protozoa of the soil, but as the zoological survey is yet incomplete we do not commit ourselves to any particular organism or set of organisms, or to any rigid and exclusive definition of the term protozoa.

The increase in bacterial numbers following after partial sterilisation by volatile antiseptics is accompanied by an increase in the rate of ammonia production until a certain amount of ammonia or of ammonia and nitrate has been accumulated, when the rate falls. Thus two cases arise: (1) when only small amounts of ammonia and nitrate are present there is a relationship between bacterial numbers and the rate of ammonia production; (2) when large amounts of ammonia or of ammonia and nitrate are present there is no relationship. The limit varies with the composition and condition of the soil.

Complications are introduced when the soil has been partially sterilised by heat, because heat effects an obvious decomposition of the organic matter, thus changing the soil as a medium for the growth of micro-organisms. The bacterial flora is also very considerably simplified through the extermination of some of the varieties. These effects become more and more pronounced as the temperature increases, and their tendency is to reduce the numbers of bacteria. We find maximum bacterial numbers in soils that have been heated to the minimum temperature necessary to kill the detrimental organisms (about 60°C). Both bacterial numbers and the rate of decomposition in such soils approximate to those obtaining in soils treated with volatile antiseptics, and the above-mentioned relationships between these quantities also hold.

Although bacterial numbers are at a minimum in soils heated to 100°, the decomposition effected is at a maximum.

With this exception, it is generally true that bacterial multiplication may go on without increasing the rate of production of ammonia, but an increase in the rate of production of ammonia does not take place without bacterial multiplication.

The increase in bacterial numbers brought about by addition of bacteria from the untreated soil into partially sterilised soil leads to still further production of ammonia and nitrate, unless too large a quantity of these substances is already present. But the subsequent depression in bacterial numbers consequent on the development of the detrimental organisms is generally (though not always) without effect on the rate of decomposition, apparently because it does not set in until too late.

VI. "*The Partial Sterilisation of the Soil by means of Caustic Lime.*" H. B. HUTCHINSON. Journal of Agricultural Science, 1913. **5**, 320—330.

When a soil is treated with lime, either in the caustic or mild form, an improvement of its physical condition results; the treatment gives rise to a certain amount of chemical action with a liberation of nutrient substances, and also, by neutralising any acids present, provides a more favourable environment for the various classes of organisms existing in the soil.

This in itself is not sufficient to account for many of the results that are obtained in practice. Caustic lime has a recognised value as an antiseptic and, when applied to the soil, even in the presence of large quantities of calcium carbonate, has a pronounced effect in disturbing or even destroying the state of equilibrium, normally existing between the *micro-flora* and the *micro-fauna* of the soil.

The action of caustic lime has been found to be intermediate in character between that exercised by volatile antiseptics and the changes induced by high temperatures. In addition to killing many bacteria and causing the death of the larger protozoa, which would appear to exert a depressive action on the growth of bacteria, it brings about a decomposition of the organic nitrogenous constituents of the soil. It is highly probable that these decomposition products serve as nutrients for bacteria and are subsequently resolved into plant food.

The depression of bacterial activities in soils treated with caustic lime would appear to persist until all the oxide has been converted into carbonate; this is followed by a period of active bacterial growth and increased production of plant food. The inhibitory action of caustic lime on soil bacteria varies with the soil and is possibly governed by the organic matter present.

In the main, pot experiments give results similiar to those obtained in the Laboratory by bacteriological and chemical analyses.

VII. "*The Action of Antiseptics in increasing the Growth of Crops in Soil.* E. J. RUSSELL and WALTER BUDDIN. Journal of the Society of Chemical Industry, 1913. **32**.

Chemical substances are now being put upon the market for partial sterilisation of soils, and this paper is intended to afford guidance to the works chemist, who is called upon to supervise the preparation of such materials. Antiseptics may be used in practice in the following cases :—

(1) Where the crop yield is limited to the supply of nitrogenous plant food, and where therefore an increased production of ammonia in the soil is desirable.

(2) Where disease organisms and other detrimental forms are present, and the micro-organic population of the soil has lost much of its effectiveness in producing ammonia from the nitrogen compounds of the soil. Such soils are known as "sick" soils and are fairly prevalent in certain types of high farming and market gardening. To some extent also sewage sick soils come into this category.

The first case is the simplest in principle, but the most difficult in practice, from the circumstance that it is already provided for by the various nitrogenous manures on the market. Until the antiseptic treatment can be made to cost less than a dressing of a nitrogenous manure, it will have no chance against these competitors.

The second case is more difficult in principle but easier in practice because it is not provided for, and there is a clear field here for the application of antiseptics in practice.

The following is found to be roughly the order of effectiveness of a number of typical antiseptics:—

Class 1. Most effective. Formaldehyde, pyridine.

Class 2. Cresol, phenol, calcium sulphide, carbon disulphide, toluene, benzene, petrol.

Class 3. Least effective. Higher homologues of benzene (*e.g.*, heavy solvent naphtha), napthalene and certain of its derivatives.

None of these antiseptics is as good as steam, either in increasing the amount of ammonia in the soil, in killing insect and fungoid pests, or in inducing a good fibrous root development. In all trials, therefore, a steamed soil is included to set the standard of excellence previously unattained by antiseptics.

The following experimental methods have proved useful in our laboratories and may be adopted by the works chemist in sorting out possible antiseptics for practical purposes:—Some rejected glasshouse "sick" soil—the worse its character the better for the experiment—is divided into three lots, one is left untreated while the other two are treated respectively with 0·1 and 0·25 per cent. of the antiseptic, care being taken that the admixture is as far as possible perfect. Five experiments are then carried out:—

(1) Chemical analyses are made at periodical intervals extending over a month, to ascertain the rate at which ammonia and nitrates accumulate in the treated and untreated soils.

(2) At the same time, bacteriological counts are made by the gelatine plate method to ascertain the rate of development of bacteria.

(3) Some of each lot is inoculated into test tubes containing a one per cent. hay infusion, and after six days' incubation at 25°C. drops of the infusions are examined under the low power of the microscope for protozoa. If these organisms are killed by the treatment, it commonly happens that other harmful organisms are killed also.

(4) Seeds are sown in the soils and the young plants are carefully watched to observe the development of "damping off" root, knots, or other diseases.

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(5) Plants are grown right through to fruiting and the produce weighed.

VIII. "*On the Growth of Plants in Partially Sterilised Soils.*" E. J. RUSSELL and F. R. PETHERBRIDGE. Journal of Agricultural Science, 1913. **5**, 248-287.

Seven important directions have been found in which partially sterilised soils differ from untreated soils as media for plant growth.

(1) There is generally a retardation in germination but sometimes partial acceleration (*i.e.*, affecting some of the seeds only).

(2) There is generally an acceleration in growth up to the time of the appearance of the third or fourth leaves, but sometimes a marked retardation, especially in rich soils heated to 100°C. We have failed to discover the conditions regulating the retardation, and can never predict with certainty whether or not it will set in. On the whole we have observed it more frequently during dull winter days than in the brighter spring or summer days.

(3) When this retardation occurs it is accompanied by a very dark green leaf colour and either the formation of a purple pigment or a tendency for the leaves to curl towards the under side. The whole appearance is strongly suggestive of an attempt on the part of the plant to reduce assimilation.

(4) Later on the purple colour goes and the curling ceases; rapid plant growth then takes place. The subsequent growth is finally proportional to the amount of food present.

(5) Plants grown in soils heated to 100° show a very remarkable development of fibrous root unlike anything obtained on untreated soils.

(6) Plants grown on soils heated to 100° have, in comparison with those on untreated soils, larger leaves of deeper green colour, stouter stems, usually shorter internodes; they flower earlier and more abundantly, and contain a higher percentage of nitrogen and sometimes of phosphoric acid in their dry matter; the roots and stems give up their nitrogen, phosphorus, and potassium more completely to the fruit.

(7) Plants grown on soils heated to 55° or treated with volatile antiseptics show fewer of these effects; there is only rarely a retardation in seedling growth but usually an acceleration, sometimes a rapid one, succeeded by a period of steady growth which is finally proportional to the amount of plant food present. No specially marked development of fibrous root or shortening of the internodes occurs, but there is an increase in the percentage of nitrogen and sometimes of phosphoric acid in the dry matter as compared with plants raised on untreated soils, and also a more complete translocation of these materials to the fruit.

IX. *The Effect of Bastard Trenching on the Soil and on Plant Growth.* E. J. RUSSELL and S. U. PICKERING. Journal of Agricultural Science, 1913. **5**, 483—496.

Bastard Trenching as originally performed, consists of two distinct operations; loosening the lower spit of soil and digging into it farmyard manure or other fertilising material.

The experiments described in this paper were made on plots that had been bastard trenched to a depth of three spits, but not manured. The first and second spits were put back in their natural order, but

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no manure was added. The experiment, therefore, deals simply with deep cultivation effect, and is not complicated by any disturbing factors due to the operation of the manure.

The effect of bastard trenching on the soil, *when unaccompanied by manuring*, was found to be only small. Beyond a tendency to facilitate the drainage of water from the top spit to the lower spit in the clays and heavy loams, and slightly to increase the nitrates, no definite change seemed to be produced. The effect on the growth of trees appeared to depend largely on the character of the seasons following the trenching and planting, as was exemplified by the different results obtained in the same plot of ground after trenching in 1895, and after retrenching in 1910. The practical conclusion may be drawn that bastard trenching by itself, done without addition of manure to the bottom spit, is not likely to bring about any sufficient change in the soil to justify the trouble and expense of the operation. Of course, if there is a pan to be broken the case is different; but where there is no pan, the main use of bastard trenching seems to be that it affords an opportunity for adding manure or other fertilising material to the bottom spit. Unless advantage is taken of this, the real benefit of the process is missed.

X. "*The Composition of Rain Water collected in the Hebrides and in Iceland.*" N. H. J. MILLER. Journal of the Scottish Meteorological Society, 1913. [iii] **16,** 141—158.

Systematic analyses have been made for a number of years of the amounts of ammonia and nitrate in rain. The question was at one time of great interest in connection with nutrition of crops, Liebig having maintained that plants derived a considerable proportion of their nitrogen from this source. The analyses have long disproved this view and interest has now shifted to another problem: the source of the ammonia invariably found in the rain water. Samples of rain have been collected systematically from various stations in the Hebrides and in Iceland, remote from atmospheric pollution, in order to ascertain how the amounts of ammonia and nitrate compare with those found at Rothamsted. The results were as follows:—

	RAINFALL	NITROGEN				
		Per Million		Per Acre, per Annum (lb.)		
		As Ammonia	As Nitrates	As Ammonia	As Nitrates	TOTAL
	Inches	Average	Average			
Rothamsted ...	28·04	0·437	0·202	2·774	1·251	4·025
Laudale, Ardgour	88·80	0·138	0·063	2·784	1·260	4·044
Barrahead, Berneray ...	35·28	0·145	0·138	1·164	1·104	2·268
Shillay Monach Islands, N. Uist.	48·36	0·115	0·054	1·260	0·588	1·848
Butt of Lewis, Stornaway ...	41·19	0·039	0·033	0·361	0·305	0·666
Vifilsstadir, Iceland	38·34	0·091	0·030	0·802	0·263	1·065

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All these samples contain ammonia and nitrate, although the amounts are low. Indeed, those from the Butt of Lewis and Vifilsstadir are the lowest hitherto recorded, the amount of ammonia in the Butt of Lewis rain being even less than was found in the southern regions by the Charcot expedition.

Seeing that ammonia is always present, it is important to ascertain where it comes from. The old theory of Boussingault, that atmospheric ammonia is derived from the sea, and the more recent one of Schloessing, that tropical seas give up ammonia to the air, are not supported by any analyses of rain collected near the sea in tropical countries, all of which show less ammonia than is found at Rothamsted. The only possible explanation seems to be that the soil, or at any rate arable soil, is continually giving up some of its ammonia to the air. So that instead of the rain contributing three or four pounds to the acre, it seems more probable that it is merely restoring some portion of the ammonia which the soil has previously lost.

XI. "*The Excystation of Colpoda Cucullus from its Resting Cysts, and the Nature and Properties of the Cyst Membranes.*" T. GOODEY. Proceedings of the Royal Society, 1913. **86 B**, 427—439.

This research has shown excystation is brought about in consequence of the dissolution of the cyst membrane by an enzyme, and an attempt has been made to follow out the main steps of the process.

The cyst membranes of *Colpoda cucullus* consist of the outer ectocyst and the inner endocyst, and the reactions of each have been studied. The endocyst appears to be of carbohydrate nature, but it differs from any other carbohydrate and appears to be new. The name "Cystose" is suggested for it. During excystation the endocyst is set free by the rupture of the etocyst, and the *Colpoda* liberates itself by the rapid digestion of the endocyst by means of an enzyme which it secretes. This enzyme differs from diastase and other known enzymes, and is named Cystase. Full details are given in the paper of the tests adopted and the results obtained.

XII. "*Soil Protozoa.*" K. R. LEWIN and C. H. MARTIN. Nature, 1914. **92**, 632 (Feb. 5, 1914).

A method of obtaining permanent preparations of protozoa in the state in which they are living in the soil.

The fixative hitherto used in our experiments has been picric acid in saturated aqueous solution, but we have since found this reagent to be less serviceable in the case of clay soils than the following mixture:—Saturated aqueous solution of mercuric chloride, 1 pt.; methylated spirit, 1 pt. The soil should be crumbled into this fluid, and mixing is best accomplished by gently shaking the containing vessel, care being taken to avoid making the clay component of the soil pass into suspension.

A delicate film containing protozoa appears on the surface of the liquid, and this can be removed by floating cover-slips over it, and stained by the usual methods.

OTHER PUBLICATIONS.

The following other publications have been issued during the year :—

"*Guide to the Experimental Plots. Rothamsted Experimental Station.*" 2nd Edition, 1913. John Murray, 1/- net.

"*Yellow Rattle as a Weed on Arable Land.*" WINIFRED E. BRENCHLEY. Journal of the Board of Agriculture, 1913. **19**, 1005—1009.

"*The Complexity of the Micro-organic Population of the Soil.*" E. J. RUSSELL. Science, 1913. **37**, 519—522.

[A reply to certain American criticisms of the work of Russell and Hutchinson.]

"*Chrysanthemum Growing in Partially Sterilised Soils.*" E. J. RUSSELL. Transactions of the National Chrysanthemum Society, 1913.

[An account written for nurserymen of experiments showing the effect of partial sterilisation on the growth of chrysanthemums, and in particular that the partial sterilisation of old chrysanthemum compost renders it again suitable for use.]

"*The Fertility of the Soil.*" E. J. RUSSELL. Cambridge Manuals of Science and Literature. 1/- net.

[A general account of the present position of soil fertility problems.]

MONOGRAPHS.

It is proposed to bring out a series of monographs in which the members of the Staff will discuss the particular problems they have been investigating, as soon as sufficient material has accumulated to render such a course desirable. Two have already been written :—

"*Soil Conditions and Plant Growth.*" E. J. RUSSELL. Longmans & Co., 5/- net.

"*Inorganic Plant Poisons.*" WINIFRED E. BRENCHLEY. Cambridge University Press. (Ready shortly.)

DATES OF SOWING AND HARVESTING, 1913.

(*For Meteorological data, see page 25*).

Crop.	Field.	Variety.	Sowing began.	Cutting began.	Carting began.	Carting ended.
Barley	Gt Knott Wood	Archer's Stiff Straw ... / Plumage Cross	Mar. 7	Aug. 20	Aug. 27	Sept. 8
Ley	,, ...	Red Clover, Alsike and Bents	May 8, '12	Jun. 26 / Sept. 9	June 30 / Sept. 17	July 4 / Sept. 18
Dredge Corn ...	Lit. Knott Wood	Abundance Oat & Archer Barley	Apr. 9	Aug. 29	Sept. 11	Sept. 13
Oats, Spring ...	,, ...	Abundance	Mar. 12	Aug. 18	Sept. 10	Sept. 10
Oats, ,, ...	Fosters ...	,, ...	Mar. 13	Aug. 16	Sept. 9	Sept. 9
Oats, Winter ...	West Barn ...	Grey Winters	Oct. 12, '12	July 24	Aug. 16	Aug. 16
Barley	Hoos	Archer's Stiff Straw	Mar. 6	Aug. 22	Aug. 28	Aug. 29
Swedes	Little Hoos ...	Sutton's Magnum Bonum ...	June 20 / July 16	———	Dec. 1	Dec. 6
Potatoes	Long Hoos ...	Dalhousie, Cora, Mayfield, / King Edward, Northern Star	May 19-22	———	Nov. 10	Nov. 22
Mangolds ...	,, ...	Sutton's Yellow Globe ...	June 9	———	Oct. 28	Nov. 6
Brussels Sprouts	,, ...	Sutton's Matchless	June 16 (set)	Jan. 16, '14	———	———
Wheat	Broadbalk ...	Squarehead's Master	Oct. 19, '12	Aug. 11	Aug. 26	Aug. 26
Wheat	Sawpit ...	Ditto and Red Standard ...	Oct. 25, '12	Aug. 18	Sept. 8	Sept. 8
Barley	Gt. Harpenden	Plumage Cross	Feb. 28	Aug. 19	Aug. 25	Aug. 25
Oats, Winter ...	,, ...	Grey Winters	Oct. 3, '12	July 22	Aug. 11	Aug. 14
Oats, Spring ...	Stackyard ...	Abundance	Mar. 11	Aug. 28	Sept. 13	Sept. 16
Grass	Park	———	———	June 23 / Sept. 11	June 27 / Sept. 19	June 30 / Sept. 19
Grass	Great (part) ...	———	———	July 1	July 9	July 17
Mangolds ...	Barn	Sutton's Yellow Globe ...	May 30	———	Nov. 12	Nov. 26
Barley	Agdell ...	Archer's Stiff Straw	Mar. 10	Aug. 22	Sept. 8	Sept. 8

CROP YIELDS ON THE EXPERIMENTAL PLOTS.

1 acre	= about	0·404	Hectare.
1 bushel	= ,,	0·364	Hectolitre.
1 lb. (pound avoir.)	= ,,	0·453	Kilogramme.
1 cwt. (hundredweight)	= ,,	50·8	Kilogrammes.
1 bushel per acre	= ,,	0·9	Hectolitre per Hectare.
1 lb. per acre	= ,,	1·12	Kilogramme per Hectare.
1 cwt. per acre	= ,,	125·6	Kilogrammes per Hectare.

CROPS GROWN IN ROTATION. AGDELL FIELD.

PRODUCE PER ACRE.

Year.	CROP.		O. Unmanured.		M. Mineral Manure.		C. Complete Mineral and Nitrogenous Manure.	
			5. Fallow.	6. Beans or Clover.	3. Fallow.	4. Beans or Clover.	1. Fallow.	2. Beans or Clover.
SIXTEENTH COURSE, 1908-11.								
1908	Roots (Swedes)	Cwt.	21·6	6·4	179·0	235·8	395·4	314·0
1909	Barley Grain ...	Bus.	11·4	10·0	17·4	22·1	26·8	33·4
	Barley Straw ...	Cwt.	10·1	11·3	12·7	16·9	18·7	23·8
1910	Clover Hay 1st crop	Cwt.	—	1·6	—	24·1	—	32·2
	Clover Hay 2nd crop	Cwt.	—	15·8	—	40·0	—	44·5
1911	Wheat Grain ...	Bus.	23·9	24·5	31·9	37·8	33·3	38·0
	Wheat Straw ...	Cwt.	20·4	21·4	28·6	33·5	29·3	32·5
PRESENT COURSE (17th), 1912-								
1912	Roots (Swedes)	Cwt.	8·2	2·3	151·7	251·9	586·6	463·0
1913	Barley Grain ...	Bus.	18·5	24·6	24·7	33·2	22·0	32·5
	Barley Straw ...	Cwt.	8·2	13·0	10·6	14·5	9·0	15·0

METEOROLOGICAL RECORDS, 1913.

(*See "Guide," 1913, page 18, Table IX.*)

	Rain. Total Fall. 5-inch Funnel Gauge.	Rain. Total Fall. $\frac{1}{1000}$ Acre Gauge.	Rain. No. of Rainy Days. $\frac{1}{1000}$ Acre Gauge.	Drainage through soil. 20 ins. deep.	Drainage through soil. 40 ins. deep.	Drainage through soil. 60 ins. deep.	Bright Sunshine.	Temperature. Max.	Temperature. Min.
	Inches.	Inches.	No.	Inches.	Inches.	Inches.	Hours.	F.	F.
Jan. ...	3·163	3·360	21	3·046	3·115	3·124	35·4	45·4	33·9
Feb. ...	0·953	1·004	13	0·658	0·767	0·785	57·4	46·3	33·4
March ...	2·406	2·518	21	0·833	0·891	0·886	103·0	50·9	36·1
April ...	3·043	3·163	20	1·409	1·528	1·537	117·0	53·5	38·2
May ...	1·721	1·806	12	0·748	0·880	0·836	206·9	62·8	43·8
June ...	1·145	1·200	8	0·003	0·021	0·025	205·6	67·1	48·1
July ...	1·190	1·291	12	—	0·001	0·001	93·0	65·5	49·9
August ...	1·444	1·576	10	—	—	—	152·8	68·6	50·7
Sept. ..	1·380	1·496	11	0·181	0·162	0·124	124·0	65·7	49·6
Oct. ...	3·382	3·494	18	2·249	2·082	2·026	106·3	58·6	45·2
Nov. ...	2·863	2·944	21	2·422	2·372	2·283	92·9	53·2	38·7
Dec. ...	0·786	0·872	14	0·379	0·360	0·302	42·5	45·0	35·8
Total or Mean	23·476	24·724	181	11·928	12·179	11·929	1336·8	56·9	42·0

For dates of sowing, etc., see page 23.

MANGOLDS, BARN FIELD, 1913.

(*See "Guide," 1913, page 13, Table VI.*)

Strip.	Strip Manures.		Cross Dressings. O. None.	N. Nitrate of Soda.	A. Ammonium Salts.	A.C. Rape Cake & Ammonium Salts.	C. Rape Cake.
			Tons.	Tons.	Tons.	Tons.	Tons.
1	Dung only ...	R.	**18·27**	**29·05**	**22·19**	**22·83**	**21·32**
		L.	4·71	7·48	7·25	7·26	6·14
2	Dung, Super, Potash	R.	**18·88**	**28·36**	**29·28**	**30·25**	**27·96**
		L.	4·53	7·93	8·23	10·22	7·25
4	Complete Minerals	R.	**4·24**	**18·25** **18·65**	**13·39**	**27·36**	**21·98**
		L.	1·47	6·59 7·62	4·53	8·84	5·24
5	Superphosphate only	R.	**4·06**	**17·38**	**5·10**	**6·73**	**8·25**
		L.	1·44	5·21	4·10	5·08	4·55
6	Super and Potash	R.	**3·08**	**14·34**	**10·79**	**19·52**	**16·52**
		L.	1·43	5·90	5·30	8·78	4·92
7	Super, Sulph. Mag. & Chloride Sodium	R.	**3·90**	**17·06**	**13·48**	**20·89**	**20·02**
		L.	1·51	6·33	5·59	8·12	5·34
8	None	R.	**3·08**	**11·39**	**4·42**	**5·76**	**7·25**
		L.	1·21	5·78	3·97	4·29	4·15

R = roots. L = leaves. Tons per acre in all cases.

HAY. THE PARK GRASS PLOTS, 1913.

(*See "Guide," 1913, page 21, Table XI.*)

Plot.	Manuring.	Yield of Hay per acre. 1913. 1st Crop.	2nd Crop.	Total.	Average 57 years 1856-1912 (1st & 2nd crops).
		cwt.	cwt.	cwt.	cwt.
3	Unmanured	12·4	0·6	13·0	20·9
12		14·9	0·7	15·6	23·9
2	Unmanured; Dung 8 years, 1856-63	15·3	0·5	15·8	28·6
5-1	(N. half) Unmanured; following Amm. Salts alone, 42 yrs. 1856-97	20·2	0·8	21·0	14·4 (1)
1	Amm. Salts alone; with Dung 8 yrs. 1856-63	26·4	2·4	28·8	35·9
17	Nitrate of Soda alone	26·6	1·9	28·5	33·7
4-1	Superphosphate of Lime	21·1	0·6	21·7	21·6
8	Mineral Manure without Potash ...	20·3	1·0	21·3	28·0
7	Complete Mineral Manure	40·6	2·6	43·2	40·9
5-2	(S. Half) Complete Mineral Manure; following Amm. Salts alone for 42 yrs. 1856-97	35·2	1·7	36·9	23·2 (1)
6	Complete Mineral Manure as plot 7; following Amm. Salts alone 13 yrs. 1856-68	36·6	3·8	40·4	37·2
15	Complete Mineral Manure as plot 7; following Nitrate of Soda alone 18 yrs. 1858-75	34·8	3·7	38·5	36·8
4-2	Superphosphate and Amm. Salts ...	45·4	2·3	47·7	33·5
10	Mineral Manure (without Potash) and Amm. Salts	44·2	2·0	46·2	47·7
9	Complete Mineral Manure and Amm. Salts	56·0	2·1	58·1	54·3
11-1	Complete Mineral Manure and extra Amm. Salts	64·3	7·2	71·5	66·5
11-2	As plot 11-1, and Silicate of Soda ...	66·7	9·3	76·0	73·3
16	Complete Mineral Manure and Nit. Soda = 43 lb. N.	42·9	3·9	46·8	46·3
14	Complete Mineral Manure and Nit. Soda = 86 lb. N.	51·9	3·8	55·7	56·9
13	Dung and Fish Guano, once in 4 years	45·4	5·1	50·5	—

(1) 15 years, 1898—1912.

BOTANICAL COMPOSITION, PER CENT.

First Crop, 1913.

(*See "Guide," 1913, page 22, Table XII.*)

Plot.	Manuring.	Gramineæ.	Leguminosæ.	Other Orders.
		Per cent.	Per cent.	Per cent.
3	Unmanured	59·0	8·7	32·3
4-1	Superphosphate of Lime ...	56·9	10·7	32·4
8	Mineral Manure without Potash	30·4	15·8	53·8
7	Complete Mineral Manure ...	69·5	15·3	15·2
6	As 7, 1869 and since	54·4	26·8	18·8
15	As 7, 1876 and since	63·7	17·2	19·1

WHEAT. BROADBALK FIELD, 1913.

(See "Guide," 1913, page 30, Table XVI.)

Plot.	Manuring.	Dressed Grain. Yield per Acre.	Dressed Grain. Weight per Bushel.	Straw per Acre.	Average for 61 years, 1852-1912. Dressed Grain per Acre.	Average for 61 years, 1852-1912. Straw per Acre.
		Bushels.	lb.	cwt.	Bushels.	cwt.
2	Farmyard Manure	25·7	64·9	29·6	35·2	34·8
3	Unmanured	5·8	63·3	4·5	12·6	10·3
5	Complete Mineral Manure	9·4	63·8	7·2	14·5	12·1
6	As 5, and single Amm. Salts ...	14·2	64·7	13·8	23·2	21·4
7	As 5, and double Amm. Salts ...	20·8	65·8	26·7	32·1	32·9
8	As 5, and treble Amm. Salts ...	28·5	65·8	38·4	36·6	41·1
9	As 5, and single Nitrate Soda ...	23·3	61·6	24·2	—	—
10	Double Amm. Salts alone	11·3	64·5	11·7	20·0	18·4
11	As 10, and Superphosphate	13·4	63·9	14·6	22·9	22·3
12	As 10, and Super and Sulph. Soda	19·0	65·1	22·7	29·1	28·0
13	As 10, and Super and Sulph. Potash	21·6	65·6	36·3	31·0	31·5
14	As 10, and Super and Sulph. Mag.	19·5	65·4	25·7	28·8	28·0
15	Double Amm. Salts in Autumn, and Minerals	22·4	65·6	22·3	29·9	29·7
16	Double Nitrate and Minerals ...	23·9	65·5	37·4	—	—
17	Minerals alone, or double Amm. Salts alone, in alternate years	*9·8	*65·0	*9·2	*14·9	*13·0
18		+21·7	+65·7	+31·1	+29·9	+29·5
19	Rape Cake alone	19·8	65·2	24·8	25·4 (2)	25·7 (2)
20 (1)	As 7, but excluding Superphosphate	11·0	65·5	17·5	—	—

* Produce by Minerals. + Produce by Ammonium Salts.

(1) Commenced in 1906. (2) 20 years, 1893—1912.

NOTE.—As in the previous season (1912), owing to the foulness of the land on the upper half of the field, the produce here recorded was that obtained on the lower half of the field only. (See notes on the crop at p. 7).

WHEAT AFTER FALLOW (without manure 1851 and since).
HOOS FIELD, 1913.

(See "Guide," 1913, page 44, Table XXI.)

		1913	Average 57 years 1856-1912
Dressed Grain	Yield—Bushels per Acre	8·3	16·0
	Weight per Bushel ...	61·8	59·4
Straw	cwt. per Acre	6·7	13·7
Total produce	lb. per Acre	1284	2536

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PERMANENT BARLEY PLOTS. HOOS FIELD, 1913.

(See "Guide," 1913, page 37, Table XVIII.)

Plot	Manuring.	1913. Dressed Grain.	1913. Weight per Bushel.	1913. Straw.	Average 60 years, 1852—1911. Dressed Grain.	Average 60 years, 1852—1911. Straw.
		Bushels.	lb.	cwt.	Bushels.	cwt.
1 O	Unmanured	21·1	55·5	9·8	12·7	8·4
2 O	Superphosphate only	34·1	56·9	13·6	19·7	10·0
3 O	Alkali Salts only	25·4	56·3	12·3	15·2	8·8
4 O	Complete Minerals	40·3	57·5	19·8	19·7	11·1
1 A	Ammonium Salts only	40·8	55·9	18·8	25·5	14·7
2 A	Superphosphate and Amm. Salts ...	64·1	57·1	27·9	38·2	22·0
3 A	Alkali Salts ,, ,, ,, ...	37·0	56·4	17·7	28·0	16·9
4 A	Complete Minerals ,, ,, ...	63·6	57·3	30·2	41·5	25·0
1 AA	Nitrate of Soda only	40·4	56·9	21·0	29·3	17·8
2 AA	Superphosphate and Nitrate Soda ...	60·7	58·0	30·7	43·1	26·3
3 AA	Alkali Salts ,, ,, ,, ...	40·3	57·3	20·9	30·0	19·3
4 AA	Complete Minerals ,, ,, ...	60·8	58·1	31·2	42·7	27·3
1 AAS	As Plot 1 AA and Silicate of Soda	50·7	57·8	26·0	32·8 (1)	19·7 (1)
2 AAS	,, ,, 2 AA ,, ,, ...	60·1	57·6	31·5	42·3 (1)	26·0 (1)
3 AAS	,, ,, 3 AA ,, ,, ...	50·1	57·7	25·8	35·2 (1)	21·7 (1)
4 AAS	,, ,, 4 AA ,, ,, ...	59·5	58·0	31·6	43·6 (1)	27·7 (1)
1 C	Rape Cake only	50·3	57·9	23·9	38·3	22·1
2 C	Superphosphate and Rape Cake ...	55·6	57·0	27·7	40·5	23·6
3 C	Alkali Salts ,, ,, ,, ...	52·9	58·2	25·8	36·9	22·3
4 C	Complete Minerals ,, ,, ...	54·9	58·3	26·9	40·5	24·5
7—1	Unmanured (after dung 20 years, 1852—71)	42·9	57·1	17·9	24·8 (2)	14·8 (2)
7—2	Farmyard Manure	61·7	57·8	31·9	47·1	29·6

(1) 48 years, 1864—1911. (2) 40 years, 1872—1911.

NOTE.—The whole of the above plots were fallowed in 1912.

BARLEY. HOOS FIELD, 1913.

(See "Guide," 1913, page 43, Table XX.)

Plot.	Manures applied to the Potatoes, 1876-1901. Unmanured since.	Dressed Grain. Yield per Acre.	Dressed Grain. Weight per Bushel.	Straw per Acre.	Total Produce per Acre.
	Previous Cropping: Potatoes, 1876-1901; Barley, 1902 and 1903; Oats, 1904; Barley, 1905-1911; Oats, 1912.				
		Bushels.	lb.	cwt.	lb.
1	Unmanured	18·4	56·6	9·2	2093
2	Unmanured 1882 to 1901, previously Dung only ...	25·6	57·2	12·2	2854
3	Dung 1883 to 1901	34·2	57·3	17·3	3930
4	Dung 1883 to 1901	33·7	57·1	17·3	3896
	Previous Cropping: Potatoes, 1876-1901; Barley, 1902-1903; Oats, 1904; Plots 5, 7, 9, Cow Peas (failed), 1905; Plots 6, 8, 10, Red Clover, 1905; 1906-1911, all Plots Red Clover; Oats, 1912.				
5	Ammonium Salts	29·0	56·6	13·8	3205
6	Nitrate of Soda	30·6	56·3	13·9	3302
7	Ammonium Salts and Mixed Minerals	44·2	57·0	20·9	4889
8	Nitrate of Soda and Mixed Minerals	43·4	57·2	20·1	4761
9	Superphosphate	33·9	56·8	15·8	3725
10	Mixed Minerals	35·9	57·2	16·6	3935

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LITTLE HOOS FIELD, 1904-1913.

RESIDUAL VALUE OF VARIOUS MANURES.

(*See "Guide," 1913, pages 45—47.*)

TOTAL PRODUCE—Grain and Straw, or Roots and Leaves, per acre, 1908 and since.

Series and Plot.	Manuring.	Swedes 1908.	Barley 1909.	Wheat 1910.	Man-golds 1911.	Wheat 1912.*	Swedes 1913.
		Tons.	lb.	lb.	Tons.	Bushels.	Tons.
A 1	Unmanured	14·0	3792	2270	11·6	19·4	8·6
2	Dung (ordinary), 1904, '8 & '12	**19·1**	5128	2572	13·9	**34·3**	8·1
3	,, ,, 1905, '9 & '13	14·5	**5544**	2681	14·1	26·9	**8·3**
4	,, ,, 1906 & 1910	15·5	4057	**2406**	12·5	29·2	1·8
5	,, ,, 1907 & 1911...	17·3	4581	2358	**15·8**	26·8	6·9
B 1	Dung (cake fed), 1904, '8 & '12	**22·4**	5362	2386	14·1	**35·6**	8·6
2	Unmanured	14·3	3862	2261	12·0	21·8	7·8
3	Dung (cake fed), 1905, '9 & '13	14·2	**6641**	2921	14·2	29·4	**6·6**
4	,, ,, 1906 & 1910...	16·9	4400	**3502**	14·4	26·5	1·5
5	,, ,, 1907 & 1911...	19·0	4298	2369	**17·1**	31·4	2·8
C 1	Shoddy, 1904, 1908 & 1912 ...	**19·7**	3969	2295	11·4	**28·4**	9·4
2	,, 1905, 1909 & 1913 ...	16·3	**4558**	2387	11·6	26·1	**10·7**
3	Unmanured	15·1	3850	2561	11·7	24·2	7·9
4	Shoddy, 1906 & 1910	19·1	4466	**3461**	14·0	30·4	5·6
5	,, 1907 & 1911	22·2	5448	2560	**14·7**	29·8	7·2
D 1	Guano, 1904, 1908 & 1912 ...	**20·9**	3608	1742	10·5	**28·8**	7·5
2	,, 1905, 1909 & 1913 ...	15·3	**6834**	2114	11·5	24·1	**10·7**
3	,, 1906 & 1910	15·9	4053	**3392**	11·1	22·5	7·4
4	Unmanured	17·4	4510	2739	11·8	26·9	6·6
5	Guano, 1907 & 1911	15·7	4014	2374	**14·2**	26·3	6·8
E 1	Rape Cake, 1904, 1908 & 1912	**19·7**	3750	2180	10·7	**27·7**	8·1
2	,, 1905, 1909 & 1913	15·1	**5203**	2242	11·7	22·3	**5·5**
3	,, 1906 & 1910 ...	14·5	3866	**3486**	11·5	22·2	6·7
4	,, 1907 & 1911 ...	15·2	4661	2516	**14·5**	25·1	7·1
5	Unmanured	14·7	4155	2784	12·7	21·1	7·0
F 1	Unmanured	14·1	4814	3166	8·7	31·6	6·4
2	Superphosphate, 1904, '8 & '12	**16·9**	4726	3223	10·9	**33·4**	8·2
3	,, 1905, '9 & '13	14·6	**4973**	2922	11·7	31·9	**8·6**
4	,, 1906 & 1910...	16·0	5280	**2682**	12·8	34·9	6·2
5	,, 1907 & 1911...	16·4	5641	3190	**14·2**	35·4	6·4
G 1	Bone Meal, 1904, 1908 & 1912	**16·7**	4445	3345	9·9	**32·8**	7·5
2	,, 1905, 1909 & 1913	14·3	**4922**	3657	9·9	32·7	**7·4**
3	Unmanured	12·7	4247	3701	9·2	29·0	3·5
4	Bone Meal, 1906 & 1910 ...	14·2	4711	**3263**	10·5	31·8	3·9
5	,, 1907 & 1911 ...	19·9	5285	3512	**12·6**	34·4	5·8
H 1	Basic Slag, 1904, 1908 & 1912	**13·8**	4182	3564	11·5	**35·7**	6·3
2	,, 1905, 1909 & 1913	13·6	**4530**	3596	12·0	33·7	**6·6**
3	,, 1906 & 1910 ...	13·6	4431	**3943**	12·5	29·1	3·4
4	,, 1907 & 1911 ...	14·4	3860	3804	**12·0**	32·5	3·1
5	Unmanured	11·4	4511	4005	10·5	30·1	2·2

The yields on the plots to which the manure was applied in any given year are printed in heavier type.
* Dressed Grain only.

COMPARISON OF THE YIELD PER ACRE OF OATS AND BARLEY GROWN TOGETHER, AND EACH ALONE, WITHOUT MANURE, AFTER SWEDES.

SAWPIT FIELD, 1912.
LITTLE KNOTT WOOD FIELD, 1913.

Plot.	Crop.	Dressed Grain. Yield.		Weight per Bushel.		Straw.		Total Produce.	
		1912.	1913.	1912.	1913.	1912.	1913.	1912.	1913.
		Bushels.	Bushels.	lb.	lb.	cwt.	cwt.	lb.	lb.
1	Oats and Barley	27·7	26·2	49·0	50·5	26·3	15·2	4318	3046
2	Oats alone ...	17·3	19·7	33·1	41·2	26·4	12·2	3593	2200
3	Barley alone ...	36·2	32·4	50·5	53·6	26·8	18·4	5081	3800

CHALKING EXPERIMENTS.

BARLEY (*Plumage Cross.*)

LITTLE KNOTT WOOD FIELD, 1913.

	Dressed Grain. Yield.	Weight per Bushel.	Straw.	Total Produce.
	Bushels.	lb.	cwt.	lb.
Unchalked	59·4	54·5	24·1	5994
Chalked ...	68·2	54·6	26·6	6760

Both plots manured with ¾ cwt. Sulphate Ammonia and 2½ cwt. Superphosphate per acre.

A General Account of the Rothamsted Field Experiments is given in *The Book of the Rothamsted Experiments*, by A. D. Hall, M.A., price 10/6 (John Murray).

A short summary is given in *The Guide to the Rothamsted Experimental Plots*, 2nd Edn., 1913, price 1/- (John Murray).

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