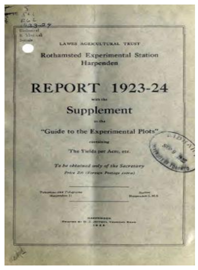
Report for 1923-1924 With the Supplement to the Guide to the Experimental Plots Containing the Yields per Acre Etc.



Report for the Years 1923, 1924

Rothamsted Research

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REPORT FOR THE YEARS 1923-24

The purpose of the work at Rothamsted is to discover the principles underlying the great facts of agriculture, and to put the knowledge thus gained into a form in which it can be used by teachers, experts and farmers for the upraising of country life, and the improvement of the standard of farming. The criterion by which the work is to be judged is its trustworthiness; if it satisfies this condition it will assuredly find its place in farm practice, or as part of the material which teachers can use in country schools, farm institutes and agricultural colleges for the education of their pupils.

The most fundamental part of agriculture is the production of crops, and to this subject most of the Rothamsted work is devoted. The problems fall into three groups concerned respectively with the cultivation of the soil, the feeding of the plant and the maintenance of healthy conditions of plant growth.

The field work at Rothamsted for many years centred round the effects of artificial manures and of farmyard manure in the production of farm crops. The farmers of Great Britain make some £14,000,000 worth of farmyard manure each year, and they spend on artificial manures a sum which is probably not much short of £8,000,000 a year. The waste of farmyard manure is known to be considerable, and it is certain that the artificials are not used as well as they could be. Numerous measurements indicate that only about 60 or 70 per cent. of the nitrogen given in artificial fertilisers is recovered in the crop; the remaining 30 or 40 per cent. is wasted. It has been estimated that the loss from wastage of farmyard manure and of artificials in the soil represents a sum probably not less than some £8,000,000 or £9,000,000 per annum.

The Rothamsted plots, while demonstrating the effects of the various artificial fertilisers on farm crops, are not in themselves sufficient to afford guidance as to the most suitable kind of manuring for any particular crop or soil type. The influence of soil and season on the effectiveness of manures is very considerable but until recently it has not been studied in detail: a beginning has now been made. Two methods of investigation are followed: In one, the analytical method, the Rothamsted data, which now extend over periods varying from 60 to 80 years, are being examined by statistical methods so as to show the effect of climatic elements, rainfall, sunshine, etc., on yields. The other is the observational method, intended to elicit the basic facts which can then be further studied in the laboratory. It is pursued in several ways. The Rothamsted plots are kept under close observation by a team of three workers, Messrs. Garner, Eden and Maskell, who view them respectively from the standpoints of the agriculturist, the ecologist and the plant physiologist. This gives information about the climatic factors but not much about the soil. Certain of the Rothamsted experiments are therefore repeated as precisely as is practicable on a number of farms chosen in different parts of the country to represent important soil and climatic conditions.

The analytical method has so far been applied only to the wheat and barley data.

Of the various climatic factors affecting wheat at Rothamsted, rainfall is the most important, accounting for some 30 to 40 per cent. of the whole climatic effect. Broadly speaking, winter rainfall is harmful, especially on land in good condition, spring rain is less harmful or even beneficial, and summer rain is harmful, but the detailed effects depend on the kind of manuring. No less than five different types of action are found on the Broadbalk field. When fertility is low, winter rain has but little bad effect; when, however, the land is in good condition, each inch of rain above the average in January reduces the harvest by one or two bushels of grain per acre. May rainfall, on the other hand, may do good, especially on land where the nitrogen supply is large relative to the potash. It further appears that wheat receiving farmyard manure is happier in a dry climate that in a wet one, while certain schemes of artificial manures work out better under wet conditions than others do.

The investigations of Broadbalk and other Rothamsted data have brought to light several interesting ways in which farmyard manure behaves quite differently from artificial manures. The variation in crop yield from year to year is less with farmyard manure than with artificials; so also is the variation in the effect of rain at different times of growth; while the land deteriorates less under the heavy strain of continuous cropping. On the rotation land clover residues are found to have a steadying effect on the yield of wheat similar to that shown by farmyard manure.

The advantage of the statistical treatment is that it enables definite expression to be given to these facts, so that the complex field phenomena become reduced to a series of single factor investigations which can be dealt with by the methods of plant physiology.

FERTILISER INVESTIGATIONS.

The fertiliser investigations are in the main reported under the various crop headings; reference must, however, be made here to certain general results of considerable interest that have been obtained.

Notwithstanding the wetness and general bad character of the seasons, especially of 1924, nitrogenous manures exerted their full effect. The average gains from the use of 1 cwt. sulphate

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of ammonia in the experiments at Rothamsted and at outside centres inspected by us were as follows :—

	1922 Rothamsted.	1923 Rothamsted.	1924 Rothamsted.	1924 Outside Centres.	Average of all Soils and Seasons to 1920
Wheat, bu. ...	3·25			4·3–6	4·5
Barley, bu. ...	5·5	4·5	8·16	3·5	6·5
Oats, bu. ...		8.3			7
Potatoes, cwt.	20	22–25	20		20
Swedes, cwt.	20	25	5–9	30	20 N. Country 10 S. Country

SIZE OF DRESSING AND TIME OF APPLICATION.

The effect of doubling the nitrogenous dressing and supplying 2 cwt. sulphate of ammonia per acre is to give a further increase in crop. In the case of cereals this second increase is not infrequently greater than the first, so that the effect of the double dressing is to give more than double the increase obtained from the single one. This was shown both in 1923 and 1924; the yields per acre were :—

	No Nitrogen.	1 cwt. Sulphate of Ammonia.	2 cwt. Sulhpate of Ammonia.	Increment in Yield for 1st cwt.	Increment in Yield for 2nd cwt.
1923 Oats, bu ...	29·2	37·3	46·5	8·1	9·2
Straw, cwt.	19	26	36	7	10
1924 Barley, bu.	23·9	32·5	42·7	8·6	10·2

In the case of potatoes, however, the second increment in yield is usually less than the first, though the total effect of the higher dressing still remains profitable because of the higher value of the potato crop.

The results have been, in tons per acre :—

	No Nitrogen.	1½ cwt. Sulphate of Ammonia.	3 cwt. Sulphate of Ammonia.	4½ cwt. Sulphate of Ammonia.	Increment in Yield for 1st dose.	2nd dose.	3rd dose.
1923 ...	12·0	13·7	15·1	14·8	1·7	1·4	Nil
1924 ...	8·0	9·5	9·4	—	1·5	Nil	—

The effect of the nitrogenous dressing depends on its time of application. For cereals it has happened that the later dressings, especially when large, have been more effective than the earlier ones (p. 118). For potatoes it has hitherto always happened at Rothamsted that the application of the sulphate of ammonia with the seed has been more effective than the later top dressing when the plants are showing through the ground. Swedes appear to behave in the opposite way. The physiological basis of this problem of nitrogen intake and nitrogenous efficiency is being studied by Dr. Gregory.

CHLORIDES AND SULPHATES AS FERTILISERS.

Farmers now have the choice of muriate or sulphate of potash : and they can also have the choice of muriate or sulphate of ammonia. The experiments with potassic fertilisers are described under " Potatoes." Our experience with the muriate of ammonia is that it is less effective than the sulphate for potatoes but more effective for barley. The difference depends on the rainfall during the months of March, April and May and becomes less as the rainfall increases. The average of all the results at Rothamsted has been as follows :—

	1921	1922	1923	1924
Effectiveness of muriate when that of Sulphate = 100 ... ... Corn ...	106	103	109	104
Potatoes	(112)*	95	92	100
Rainfall—March, April and May (inches)	4·08	7·38	5·64	8·95

*Crop almost failed ; 2 tons per acre only.

The chloride of ammonia has had a remarkable effect on the grain of barley as is described below.

BARLEY.

During the past three years an extended investigation into the effect of manures on the yield and quality of barley has been carried out at Rothamsted and on certain good barley farms in various parts of the country, the work being done in connection with the Research Scheme of the Institute of Brewing. The variety grown is Plumage Archer, and seed from one and the same field was used at all the centres.

The results show a considerable degree of concordance among themselves, but they differ in several important respects from the current teachings of agricultural science. It is usually recommended that the manuring for barley should be mainly phosphatic, nitrogen being given only after a corn crop and potash but rarely. Out of 30 different tests this recommendation would have involved loss of money in no less than 26. The actual yields are given on p. 114; the average reduction in yield in bushels per acre, consequent on the omission of each fertiliser during the three years 1922, 1923 and 1924, has been :—

Decrease due to omission of :—	After a straw crop.	After roots fed off.	After potatoes or beets (well manured).	Mean of all experiments.
1 cwt. sulphate of ammonia ...	5·8	3·9	6·7	5·4
3 cwt. super-phosphate	0·9	[0·5]	1·2	0·5
1½ cwt. sulphate of potash	[1·1]	1·3	1·1	0·3

(The figures in brackets are increases and not decreases.)

The reasons for this unexpected result are probably two :—

1. The modern varieties of high quality barley, such as Plumage Archer, are stiffer in the straw than the older ones, and therefore can carry larger crops of grain without risk of being lodged. Apparently, therefore, they can safely receive more nitrogenous manuring.

2. Good farmers now realise the importance of giving ample dressings of superphosphate to their root crops and sufficient of this fertiliser generally remains in the soil to satisfy the needs of the barley. Potash and phosphates intended for the seeds mixture can, of course, be applied to the barley in which they are sown. The barley may derive benefit, but the profit from these manures must come from the seeds.

One of the distinguishing features of the scheme is that all the experimental barleys are examined by expert maltsters appointed by the Institute of Brewing Research Committee, and are afterwards malted separately and the malts fully analysed.

It is shown that the use of a nitrogenous manure even after roots folded off has not adversely affected the valuation of the barley or the value of the malt, but that the omission of potash from the manure lowered some of the desirable qualities of the malt in 1922, though not apparently in 1923. At each centre the heaviest crops obtainable by manuring have been valued as high, or nearly as high, per quarter, as any other samples of the same set, and it is clear that manurial schemes can be devised which will enhance the present yield without detriment to valuation. So far as the investigation has gone it suggests that farmers using a good modern variety of barley can aim at the biggest crop that will stand, and they can use the appropriate fertiliser to secure this without fear of loss of valuation.

Thus, for the season 1923, the figures for valuation were :—

Valuation per quarter of 448lb., 1923 barleys : made January, 1924.

	Rothamsted.	East Lothian.	Eyton.	Chiselborough.	Walcott.	Warminster.	Lincs. Wolds.
1 cwt. sulphate of ammonia	57/–	49/6	49/–	47/–	41/6	52/–	42/–
No Nitrogen	56/–	49/–	50/–	46/–	41/–	52/–	41/6

A remarkable effect is produced when the chloride (or muriate) of ammonia is substituted for the sulphate. In every instance the valuation of the grain has been raised and its nitrogen content lowered. This is shown by the following table :—

Season.	Valuation of Barley. per qr. of 448 lb.		N. content of grain per cent. of dry matter.	
	Sulphate of Ammonia.	Ammonium Chloride.	Sulphate of Ammonia.	Ammonium Chloride.
1922 ...	31/–	36/–	1·647	1·602
1923 ...	57/–	58/–	1·544	1·485
1924 ...	63/6	64/–	1·517	1·495

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The result is all the more interesting in that this is the only manurial method hitherto tested which has consistently improved the quality of the grain. Other treatments have acted sometimes one way and sometimes the other, the change being usually small and unpredictable.

When yield is combined with the valuation and allowance is made for tail corn there is found to be a considerable difference in money value per acre in favour of the chloride :—

Yield (measured bushels per acre) and Money Value of Barley per Acre.

	Sulphate of Ammonium.		Ammonium Chloride.		Difference in favour of Chloride as against Sulphate.
	Yield.	Money Value per Acre.	Yield.	Money Value per Acre.	
1922 ...	36.0	136/–	35.7	156/–	20/–
1923 ...	32.5	239/–	35.6	265/–	26/–
1924 ...	29.8	238/–	29.7	249/–	11/–

In the course of the work it has become clear that the method of valuation commonly adopted does not always work out quite fairly either to the buyer or the farmer. On the loams the estimate has usually been tolerably correct; the value of the malt obtained has paid the cost of the barley, the transport, expenses and profits of malting and other charges. But on the lighter soils, the barley has not generally been as good as it looked, so that the value of the resulting malt did not pay all the charges. On the chalk and limestone soils the barley turned out better than it looked; the farmer received less than he deserved and the malt gave an additional profit to the maltster.

These results are quite intelligible. The buyer judges from certain external appearances of the barley which are on the whole correlated with the value of the resulting malt. But the correlations between the external characteristics and chemical composition are liable to be affected by changes in environment, and it need occasion no surprise that a correlation holding good on loams may be modified in one direction on a sandy soil, and in another on a chalk soil.

The malting and brewing part of the investigation lies outside the scope of Rothamsted, and is carried out entirely by the Institute of Brewing, but the Station, at the cordial invitation of the Institute, is keeping in close touch with the work.

BASIC SLAG AND GRASS LAND.

It is well known that basic slag produces excellent results on many grass fields, especially on the Boulder clays where there is much bent grass and only little wild white clover, but on a number of fields it fails to act.

Two causes of failure are already known, and methods of dealing with them have been worked out :—

(1) The land may be too sour, requiring a dressing of lime before the slag can act.

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(2) There may be insufficient potash; this may be supplied by addition of kainit, 20 per cent. potash salts, etc.

All basic slags, however, do not behave alike. Examination shows that they fall into two great groups: those in the making of which fluorspar was used: and those to which no fluorspar was added. Field experience shows that the fluorspar slags are often less effective than the others: chemical examination indicates that they contain some of their phosphate in the form of fluorapatite, a substance having little, if any, value to plants. The slags free from fluorspar, on the other hand, contain some, if not all, of their phosphate in the form of silico-phosphate, which is of very considerable value to plants. Mr. Page has developed a method for ascertaining the amount of fluorine in slags, from which can be calculated the maximum value for the quantity of fluorapatite present. Some of the results are:—

Slag No.	(1) Total Phosphate, per cent. of slag.	(2) Citric Solubility, per cent. of total phosphate.	(3) Fluorapatite (little value) per cent. of slag.	(4) Silico and other phosphates (much value) per cent. of slag.
1	42·5	77·2	1·4	41·1
2	29·2	91·0	Nil	29·2
3	28·9	16·4	26·9	2·0
4	25·1	98·4	Nil	25·1
5	24·3	30·0	22·0	2·3
6	21·1	27·7	12·3	8·8
7	19·8	70·9	Nil	19·8
8	18·0	81·3	1·3	16·7
9	17·8	37·7	17·1	0·7
10	17·2	78·7	1·4	15·7

(1) Total phosphoric oxide (P_2O_5) multiplied by 2.18 to convert into the equivalent quantity of tricalcic phosphate ($Ca_3(PO_4)_2$).

(2) Percentage of the total phosphoric oxide (P_2O_5) which is soluble in the official 2% citric acid solution.

(3) Calculated from fluorine present, assuming all to be in form of fluorapatite.

(4) The remaining phosphate.

The slags are arranged in order of total phosphate and therefore approximately in order of price. Reference to the last column shows, however, that they differ considerably in their content of effective phosphates. Thus slags 2 and 3 are rated equal by the ordinary analysis and might be offered at the same price by a merchant acting in perfectly good faith and honesty. In the field tests No. 3 is less effective than No. 2. Mr. Page's method shows that it may contain most of its phosphorus in the non-effective form of fluorapatite, while No. 2 contains all its phosphates in the effective forms. The citric solubility test discriminates between these slags but its indications are not always very clear. The fluorine method promises to be more helpful.

The new method does not, however, enable the slag to be completely characterised and there are still differences in effectiveness which cannot be explained. Slags No. 1, 6, 7 and 8 were compared in the sheep grazing trials at Rothamsted over a period of four years. The gains in live weight of sheep over those obtained on the unmanured plots have been :—

	1921	1922	1923	1924	Total benefit in 4 years., lb. live weight per acre. Slagged over unslagged land.
Slag No. 7	50	19	62	18	149
,, ,, 8	Nil	Nil	Nil	30	30
,, ,, 6	Nil	Nil	15	Nil	15
,, ,, 1	Nil	21	7	Nil	28

It is obvious that No. 7 is by far the most effective of these slags, being better even than No. 1 which was known to act well on other soils, but no chemical test so far tried would show this superiority to a prospective purchaser. At the time we obtained the slag neither the makers nor ourselves knew or even suspected that it would prove any better than No. 8 or as good as No. 1, nor can we yet explain why it should be so. It seems clear that somewhere in its history this slag received some treatment which, if it could be repeated on other slags, might greatly enhance their agricultural value. A possible clue has been furnished by the manufacturers and an observation has been made in the chemical laboratory which may furnish the solution of a very attractive problem.

A third important chemical factor has been discovered during the past season by Dr. Brenchley and Mr. Page. Some of the slags examined were found to contain substances harmful to the plant. This does not, of course, mean that they actually damaged the crop : what happened was that in these particular slags the beneficial effect of the phosphate present was in part counteracted by the harmful substance. All these problems are being followed up and the co-operation of the slag makers is secured through the Permanent Basic Slag Committee of the Ministry of Agriculture. In the meantime farmers who have applied slag to their grass and obtained disappointing results are requested to communicate the facts to the Director.

POTATOES.

The experiments with the different potash manures begun in 1921 have been continued (p. 120). The muriate and the sulphate of potash behave nearly but not quite alike, the muriate giving sometimes a slightly better and sometimes a slightly less yield than the sulphate. The determining factor is partly rainfall, the sulphate tending to give the higher yield in drier conditions and the muriate in wetter, but there is something beside this, for in 1924 the sulphate came out the better in spite of the wetness of the season.

Addition of other chlorides (*e.g.*, salt) to the muriate, is, however, injurious; neither kainit nor sylvinite gave the full benefit expected from the potash because of the harmful effect of

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the salt. This is to some extent mitigated by additions of dung, but the crop always falls below that obtainable from the muriate or the sulphate. The results at Rothamsted are :—

YIELD OF POTATOES WHEN SULPHATE OF POTASH IS USED = 100.

	1922		1923		1924	
	Without dung.	With dung.	Without dung.	With dung.	Without dung.	With dung.
Muriate of Potash	106	98	98	105	98	99
Sylvinite	89	—	87	84	108	105
Rainfall (March-May inclusive).	4.08		5.64		8.95	

These fertilisers affect the quality of the potatoes. Of the complete manured plots, those receiving sulphate of potash produce tubers with the highest percentage of dry matter.

Potassic Fertiliser Used.	Percentage Dry Matter of Potato Tubers.				
	Rothamsted. 1922	Rothamsted. 1923	Reaseheath. 1922	Seale-Hayne. 1922	Usk. 1923
Sulphate ...	24·26	21·73	21·68	24·4	23·6
Chloride ...	22·02	20·85	19·63	22·3	22·5
Low Grade Salts	19·68	17·87	17·28	22·7	21·0
No Potash ...	23·07	20·65	17·62	25·7	22·1

The tubers grown with low grade potash salts (kainit, sylvinite) are the lowest in dry matter content, coming out even below those grown without potash.

The percentage of starch in the dry matter is an important quality factor, and in all tubers so far analysed the value comes out higher for the sulphate of potash than for any of the other salts.

Potassic Fertiliser Used.	Yield in tons per acre.	Dry Matter per cent. in Tubers.	Starch per cent. in Dry Matter.	Starch. Tons per acre.
Sulphate	8.30	24·26	65·84	1·325
Chloride	8·32	22·02	64·00	1·175
Low Grade Salts ...	8·06	19·68	58·20	0·925
No Potash	2·47	23·07	57·16	0·325
Control	2·98	23·36	58·20	0·405

Magnesium sulphate continues to give interesting results; its effect on potatoes has been beneficial at several centres though we cannot yet explain why.

Complete Artificials.	Rothamsted. 1922 No Dung.	Rothamsted. 1923 No Dung.	Rothamsted. 1923 Dung.	Blaydon. 1922 No Dung.	Blaydon. 1922 Dung.	Walbottle. 1922 No Dung.	Walbottle. 1922 Dung.	Newton Abbot. 1922 Dung.
No Magnesium Sulphate ...	100	100	100	100	100	100	100	100
With Magnesium Sulphate ...	102 97	104 108	104 104	108	114	118	129	117 120

GREEN MANURING.

The importance of increasing the amount of organic matter in the soil is widely recognised, and experiments have been carried out at Rothamsted for some years to determine the best ways in which this could be done. Mr. Page has been studying green manuring, and he has now been able, thanks to the intervention of the Research Council of the Royal Agricultural Society, to arrange for a number of experiments at outside centres, and thus to obtain direct information on the extent to which soil and climatic factors influence the method.

In practice two kinds of green manuring are possible, though they are not always practicable :—

1. Summer catch crops may be turned in before the winter corn.
2. Winter catch crops may be turned in before roots.

In general, the first method can be practiced only on fallow land, early ploughed seeds leys, or land that has carried a crop harvested early, such as a silage or soiling crop. The eastern counties appear to offer the best opportunities for success.

Trials of this method, using mustard as the green crop, are in progress at six centres, one in the west (Gloucestershire), and five in the east (Kent (2), Suffolk, Beds. and Northants.). The results of the test at Rothamsted give a forcible illustration of its value. Mustard was sown on the bare fallow after cleaning on 20th August, 1923. It was turned under on October 18th, and winter oats were drilled at once. The yields of oats in August, 1924, were as follows :—

Basal Manure.	Yield of Oats, bu/acre.		Increase due to Mustard.	
	After Mustard Ploughed in.	After Fallow (no mustard)	Bu.	Per cent.
None	43·3	25·0	18·3	73
5 tons town refuse	51·8	27·1	24·7	91
10 ,, ,, ,,	49·3	30·6	18·7	61
Average	48·1	27·6	20·5	74

The turning in of mustard thus added, on the average, 20 bushels per acre to the crop. The cost per acre for mustard seed and the extra operations involved in drilling and turning under amounts to 18/-, whilst the increased yield of oats was worth 79/6 per acre, without reckoning the value of the extra 9 cwts. of straw per acre.

The turning in of winter catch crops before roots is probably of even greater practical importance. Climatic factors play a great part since the green crops have to pass through the winter : if this is too cold, crops sown in the autumn do not usually make sufficient growth, by the time when the land needs to be prepared for roots, to produce any marked effect on the root yield. It is probably only within the region, with an average winter temperature exceeding 40° F. and an annual rainfall between 30 and 40 inches, that the present set of autumn sown green crops can as a rule be successfully grown for turning under in the spring before the roots. The fact that the corn harvest is earlier in this part of the country, so that green crops can be sown earlier, also helps. Outside of this region autumn sown green crops do not in general make enough growth by the spring to be useful for green manuring purposes; this has happened at Rothamsted for three successive seasons (1921-1924).

The problem therefore arises of finding a system of green manuring for roots which is applicable to the colder northern and eastern districts.

Undersowing of green crops in the corn, and possible new crops are being tried : and at certain centres the relative economic values of folding the green crops to sheep, and of turning them in for manure, are being ascertained.

THE LEGUMINOUS CROPS.

Considerable attention has been devoted to the leguminous crops, owing to their great importance in the rotation and as stock foods. The effect of manures applied to the barley on the clover sown in is shown on pp. 114, 115. Sulphate of ammonia had no bad effect on the clover although it increased the yield of barley. We have met cases where the application of sulphate of ammonia to barley reduced the yield of the clover, but in our experience this happens only when the land badly needs lime, and it is attributable to the increased acidity which sulphate of ammonia is liable to produce on such soils. The phosphate apparently had no action while the potash exerted a distinct residual effect, giving an additional 6 cwts. of clover hay in 1924 and 12 cwts. in 1923. The results indicate that potash should be applied to the clover if the barley crop has been good, unless it has already been given to the barley.

Inoculation of leguminous crops, especially lucerne.

Ever since 1890, when Hellriegel and Wilfarth discovered that leguminous plants live in association with micro-organisms inhabiting the nodules on their roots, efforts have been made to improve the growth of leguminous crops by adding the appropriate organisms to the soil. Some successes were obtained on the Continent, but the method failed in this country; the results at Rothamsted in 1906 and 1907 were not then considered sufficiently good to justify extension to farm practice.

There is no doubt, however, that for certain crops the principle is sound; the failure of inoculation in Britain must be attributed to the lack of compliance with the conditions necessary to success. During the past three years the whole subject has been re-examined in the Bacteriological Department.

The subject affords an admirable illustration of the way in which a practical problem of great importance remains unsolved, in spite of many empirical efforts, until the underlying principles have first been studied and a solid groundwork of definitely ascertained facts has been obtained.

The failure of inoculation in many cases has been traced to the circumstance that the organisms were already present in the soil, but some condition essential to the growth of the plant was not realised, and the deficiency could not be remedied by merely adding more of the organisms.

Further, it was shown that many of the cultures sent out to farmers died on the way, so that the material used for inoculation was useless. This difficulty has been overcome by devising means whereby the organisms could be transported alive. The need for fresh, active stocks of the organisms available for farmers at short notice has been met by devising a medium in which the organisms grow much more quickly than in the older media.

The organism cannot flourish in soils having too great a degree of acidity; a usual limit corresponds with the pH scale number 6.0.

A much more difficult problem is being attacked in the Bacteriological Department. The organisms were found to pass through a life cycle including motile stages in which they can travel to the plant, and non-motile stages in which they cannot. The non-motile stage can, however, be made to change into the motile stage by certain treatments, especially the application of phosphates; this is no doubt one reason for the remarkable effect of basic slag in increasing the growth of clover on certain soils. Messrs. Thornton and Gangulee have measured the time required for the organisms to assume the motile form in the soil, and the rate at which they then spread through it. On the basis of these various facts, Mr. Thornton has been able to devise a method of inoculating which ensures an earlier commencement of spread of the organisms in the soil, and therefore a better chance of infection of the roots, than in any method previously tried in this country.

The Research Committee of the Royal Agricultural Society has made a grant to Rothamsted which is allowing extensive trials to be carried out at some thirty centres scattered throughout England to test the value of the method for lucerne. It is too soon to speak definitely about the results, but already inoculation has proved of considerable value in new districts where the crop has not previously been grown, and it has in places doubled the growth in the first year as compared with the uninoculated plots, besides giving vigorous plants which promise to survive and come out in full strength in the summer. Meanwhile the purely scientific study of the organism and of its relation to the plant is being steadily pursued with the object of getting further information. Exceptions and difficulties will inevitably arise as soon as farmers adopt inoculation as a general practice, and the surest way of minimising the resulting losses and inconveniences is to obtain the fullest possible knowledge of the whole process.

Two investigations have been carried on which cannot fail to have important bearings on the practical problem. The first, which is still in hand, is concerned with the influence of straw on the formation of nodules. Attention was directed to this by the observation that farmyard manure is more effective in increasing the growth of clover than any dressings of artificial manures yet tried. In pot experiments unrotted straw greatly increased the numbers of nodules formed on each plant; there was, however, no increase of yield till phosphates were added. A dressing of straw and phosphate has been found in field tests to be an effective fertiliser for beans and affords a method of increasing the organic matter of the soil which might find useful application in practice.

The second investigation brings out the fact that the plant is just as important as the organism in the partnership. It arose as a result of Miss Warington's important discovery that many leguminous plants fail to grow unless supplied with traces of boron. Dr. Brenchley and Mr. Thornton, taking the broad bean as their example, showed boron to be essential to the proper functioning of nodules on its roots. In the normal course, conducting vessels grow out from the vascular system of the plant root and enter the nodule. Along these vessels food materials are brought from the plant to the bacteria, and the products of their activity are carried back to the plant. The vessels thus act as conduit pipes, connecting the organisms with the plant and making the partnership effective. In the absence of boron these vessels do not form or are very weakly developed. The organisms, losing their normal source of food, become parasitic and destroy the plant protoplasm, being then harmful instead of useful to the plant. The work thus shows that the organism is a potential parasite; only by the nice adjustment occurring in the healthy plant can the beneficial partnership be maintained.

In most soils there is apparently sufficient boron to allow of full development. But instances are on record in Japan, and possibly elsewhere, where peas, which do not need boron, will grow while other leguminous plants which need it will not. In these soils there might be a boron deficiency. The more important result emerges that the successful growth of a leguminous crop depends on three conditions: presence of the proper organisms and soil conditions necessary for their growth; the proper nutrition of the plant; and development of the conducting system linking the organisms in the nodule with the circulating system of the plant.

Liming.

The effect of lime on sour arable land and on certain kinds of grass land is well known and farmers are frequently advised to use more of this substance. But directly they begin to follow the advice they are faced with the difficulty that analysts cannot as a rule inform them just how much lime per acre they should apply, and a round figure of one or two tons per acre is often suggested. The recommendation suffers from the defect that no farmer can afford to supply two tons per acre if one ton is sufficient, apart from the consideration that too large a dressing may injure the crop or the soil.

Various empirical methods have been devised from time to time to give some idea of the quantities needed, but the different tests give different results, and in absence of definite knowledge

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as to how they act or what they really indicate, it is impossible to arrive at any satisfactory conclusion.

The method hitherto used in this country was devised in 1913 by Drs. Hutchinson and MacLennan in these laboratories. It has served a useful purpose, but it suffers from the drawback that it is considerably affected by three soil factors, none of which it accurately measures: the hydrogen ion concentration: the "buffer action": and the neutral salt action in the soil. These are separated in the modern electrometric method used by Mr. E. M. Crowther in the Physics Department. The older method, however, has the merit of convenience, and it has now been improved by the introduction of certain empirical corrections.

Measurements at Rothamsted and at Woburn have shown that the effects of soil acidity induced by long-continued and excessive use of sulphate of ammonia are manifested as far down as 3 or 4 feet in the soil, and are not confined to the surface 9 inches.

Soil Chemistry, Physics and Microbiology.

In the Chemical Department work has been done under Mr. Page on the organic matter of the soil, which plays so important a part in soil fertility. Mr. du Toit has adduced evidence that humus is formed from lignin and not from the carbohydrate materials, cellulose, etc., to which its origin was formerly assigned. It is true that these substances can be made in the laboratory to yield black products looking like humus, but chemical examination shows that only the lignin product closely resembles the substance actually present in the soil. The problem is difficult and necessitates much further study, but the information is needed in order to discover what are the useful organic constituents of the soil. It is expected that this work will find application to green manuring.

Another important line of enquiry is in connection with the bases in the soil. It is shown that many of the important soil properties depend on the presence of a complex calcium combination: indeed, of all elements in the soil, calcium is probably the chief in agricultural significance. This calcium can be replaced by hydrogen under conditions of high rainfall: the soil then readily becomes acid. Alternatively it can be replaced by sodium in dry regions where irrigation water containing sodium salts is used (as not infrequently happens). The sodium combination differs chemically and physically from the normal calcium combination, and it is infertile when treated by the normal agricultural methods: it might conceivably be fertile if treated by methods specially suited to its properties. But its gravest defect is that it is easily hydrolysed, forming sodium carbonate, a very serious plant poison. Or, again, the calcium may be wholly or partially replaced by magnesium or potassium. Each of these products behaves unlike the calcium product when subjected to ordinary treatments and therefore is regarded as infertile. This new knowledge will undoubtedly prove useful in devising means of dealing with difficult soils: the Weald and Lower Lias clays deserve study from this point of view.

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SOIL TILTH AND CULTIVATION.

In the Physical Department the studies of tilth under Dr. Keen are being continued. The work includes exact laboratory studies of the physical factors involved in tilth and also measurements of the drawbar pull when land is ploughed under varying conditions. An investigation of this kind is prolonged but already interesting results are emerging. The purpose of the laboratory work is to develop the science of soil physics on which ultimately a scientific soil cultivation can be based, just as scientific manuring is based on chemistry and plant physiology. Mr. Haines has completed some important pioneering work on the physical properties directly concerned in ploughing: cohesion and plasticity of soil, and surface friction between soil and metal. But in order to get very far with the investigation it is necessary to study the underlying causes, and so researches are carried out which, while less obvious in their bearing, are no less, but possibly even more, essential than those just mentioned. Good tilth in soil is traditionally associated with the formation of compound particles or soil aggregates. These in turn are determined by the colloidal properties of the soil: and so it comes about —as often in agriculture—that progress in a practical problem cannot be made until some abstruse and apparently wholly irrelevant scientific problem is solved. The friction between the plough and the soil is a practical problem of the first importance: but it cannot be adequately studied without a proper understanding of the colloidal properties and the ultimate constitution of the soil. The three methods of investigating these in the Physics laboratory are:—

(*a*) A study of the relative intensity of the forces holding soil particles together when the soil has been subjected to a variety of treatments that simulate field conditions. The method adopted is the measurement of the amount of soil in suspension after shaking with water under definite conditions;

(*b*) Direct measurements of the vapour pressure at different moisture contents of soils treated in various ways;

(*c*) Indirect measurements of the vapour pressure using a method that depends on the lowering of the freezing point depression of benzene in contact with the moist material that has an affinity for water.

The results show that many of the observed properties of soils can be interpreted on the assumption that the colloidal material is permeated with minute capillaries, analogous to those investigated by Zsigmondy and Anderson in silica gel. They also indicate that compound particles are formed in soil at comparatively high moisture contents, and that once formed they are not easily disintegrated. This last conclusion has led to a somewhat disconcerting discovery. It is found that complete dispersion of soil is frequently not attained in the standard method of mechanical analysis: hence many of the recorded

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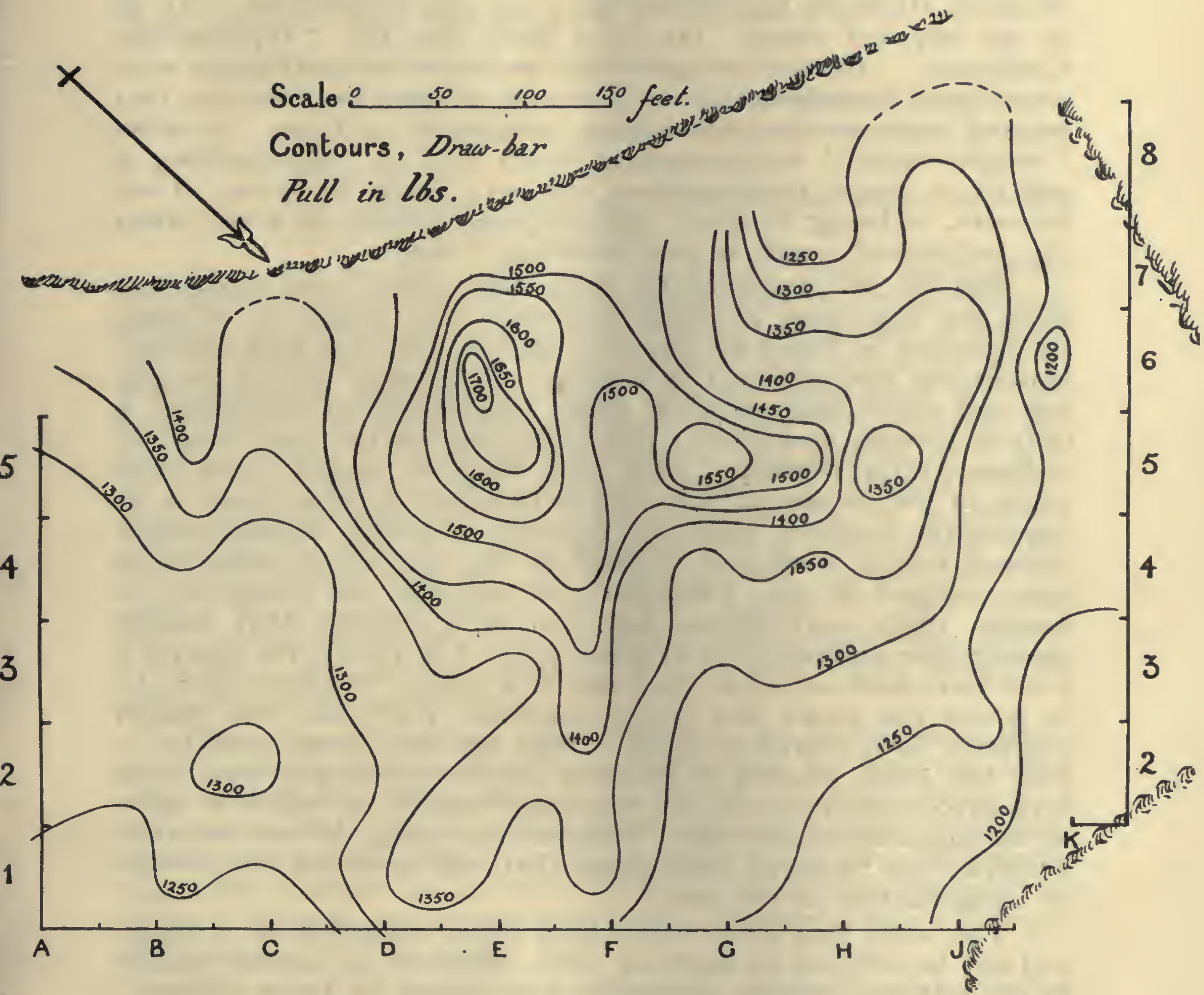

FIG. I.—Diagram showing the variation in drawbar pull over an area that to visual inspection appeared uniform.

data are erroneous. Nor is dispersion complete in the standard dilution method for counting soil organisms, and the results of any given plating are liable to the error of counting as a single organism a group or colony on an undispersed soil aggregate.

A further consequence of great interest to the expert has also emerged: certain of the so-called " constants " of the text books, such as the Hygroscopic Coefficient, the Wilting Coefficient, Moisture Equivalent, etc., are not " constants " at all in the physical sense. Dr. Puri finds that the " Hygroscopic Coefficient " (the percentage of soil moisture in equilibrium with a saturated atmosphere) is so inherently difficult to determine that marked discrepancies are almost inevitable. These so-called " single value " measurements which aim at characterising a soil by a single determination are very liable to error. One, however, is being studied: the moisture content of a soil when the well-mixed mass is just becoming sticky.

But all this fundamental work takes time, and meanwhile there are important practical problems for which a working solution can be found by empirical means. On the field side Mr. Haines has obtained further readings of drawbar pull in ploughing and cultivating, as done under ordinary farm conditions, a criterion which necessitates the dovetailing of the work into the ordinary farm routine. This year detailed studies have been made of the causes of the irregularities of drawbar pull in an apparently uniform piece of ground. Careful measurements showed that a level field uniform to the eye which would have been selected by any Committee as suitable for ploughing or tractor trials nevertheless had soil irregularities that caused considerable differences in drawbar pull. The results for Sawyer's Field have been set up in the form of a contour diagram (Fig. 1), in which the peaks and ridges represent high, and the valleys represent low, drawbar pulls. Had the field been used for a test, the areas allotted to different implements might have been very favourable to some and very unfavourable to others in spite of the apparent uniformity. Methods are being devised whereby a survey can be made beforehand that will show the distribution of irregularities in the soil.

The work has also shown how much reduction in drawbar pull can be effected by applying lime, limestone or organic matter to the soil, and how to obtain the best effects by these methods. Further, it has been found that the friction of ploughing can be reduced by an electric device simple in principle and only awaiting exploitation to become important in practice.

Much work is done in the Physics Department in studying the moisture relationships of the soil. Measurements conducted in large cylinders filled with Rothamsted soil show that little water rises to the surface from the subsoil when the ground water falls to 4 or more feet below the surface. A definite relation was found between the potential evaporating power at the surface and the change in ground water level. This work will be greatly facilitated when the continuous recording devices now being devised are installed.

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THE MICRO-ORGANISMS OF THE SOIL.

Reference has been made in previous Reports to the important part played by the soil micro-organisms in determining the productiveness of the soil. These organisms break down the organic matter in the soil, the plant residues, farmyard manure and other organic manures, converting them into useful plant foods. They effect at least three kinds of action which are directly beneficial to the plant:—

1. The production of nitrates.
2. The decomposition of plant material producing structureless compounds having valuable colloidal properties.
3. The decomposition of intermediate products which would be toxic to plants.

The most striking result brought out by recent observations has been the fluctuation of the micro-organisms in natural field conditions. There are two-hourly fluctuations, recognised at present only in the case of bacteria, which have been measured in the Bacteriological Department. Superimposed upon these are daily fluctuations which are known to affect not only bacteria but protozoa also, the level of numbers for any species at 9 a.m. varying from day to day. Further, there are seasonal fluctuations; a great rise in spring, a fall in summer, a rise in autumn, and a fall in winter; bacteria, protozoa and apparently also algae and fungi being affected. It is not known whether there are annual fluctuations, though this would appear not improbable. The phenomena are not confined to soil micro-organisms; similar fluctuations are recorded for plankton and pond algae, though the data are not so complete.

The cause of the daily and probably of the hourly fluctuations of bacteria is fluctuation of the number of the amœbæ which feed upon them. Why the amœbæ should fluctuate was for long a mystery; Mr. Cutler and Miss Crump have thrown some light upon it by showing that rate of reproduction of amœbæ depends upon the number of bacteria present; when the bacteria fall below a certain level no division of the amœbæ occurs; it begins only when they rise above this.

The spring and autumn increases in number, however, affect bacteria and protozoa alike, so that some other cause is apparently operating.

All this work has been possible through the elaboration by Mr. Cutler of methods of counting protozoa in the soil, and the development by Mr. Thornton of a plating medium in which bacterial colonies would develop uniformly and without the spreading which in the older technique suppressed some of the slow growing forms. The medium has the further advantage of being prepared from pure substances so that it can be reproduced with precision whenever desired, and it has thus been possible to apply a statistical formula whereby the degree of accuracy of the plate counts can be estimated.

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The quantitative measurements give a much clearer picture than was hitherto possible of the character of the soil population. The average numbers obtained in the high activity period of spring and the low activity period of the winter are as follows :—

		Numbers per gram of soil.	Approx. weight. lbs. per acre.
Bacteria	High Activity ...	45,000,000	50
	Low ,, ...	22,500,000	25
Amoebae	High Activity ...	280,000	320
	Low ,, ...	150,000	170
Flagellates	High Activity ...	770,000	190
	Low ,, ...	350,000	85
Ciliates	High Activity ...	1,000	—
	Low ,, ...	100	—

The weight (also the volume) of the protozoa in the soil considerably exceeds that of the bacteria in spite of the high numbers of the latter.

It is more difficult to ascertain whether the production of plant food fluctuates in the same way as the numbers of organisms. There are undoubted fluctuations, but more data are required before the proof becomes as rigid as it is for bacteria.

There is definite evidence that crops obtain only part of the possible food supply, much of the rest being taken by soil organisms and thus rendered unavailable. One cannot as yet say which are the worst offenders in this respect; at present suspicion attaches to the algae, and the laborious task of clearing up the problem is being carried out by Dr. Bristol Roach.

CONTROL OF THE SOIL ORGANISMS.

The knowledge of the soil organisms gained in our laboratories is allowing of a steadily increasing degree of control. There are at present four directions in which large scale tests are carried out.

1. Inoculation of lucerne by the appropriate micro-organisms.
2. Conversion of straw into a useful manure by the cellulose decomposing organisms.
3. Control of the plant food production process by partial sterilisation methods.
4. Control of plant disease organisms by similar methods.

Of these, inoculation has already been discussed on p. .

Artificial Farmyard Manure.—The production of manure direct from straw is now being carried out on the large scale. In the past season no less than 3,000 tons of straw and like material were treated in Britain alone in addition to much larger quantities treated abroad.

The method of making artificial farmyard manure is based on the facts that the necessary organisms are already present and need only suitable conditions to call forth their activities. Food stuffs (especially nitrogen compounds and phosphates) are supplied, along with calcium carbonate to obviate acidity, and decomposition then proceeds rapidly, converting waste useless straw and other materials into valuable manure.

The large scale development is carried out by the non-profit making " Adco " syndicate, of which Lord Elveden is Chairman, thus relieving the Station of much exploitation work for which it is not suited. The numerous scientific problems constantly arising out of the field experience are studied by Messrs. E. H. Richards and R. L. Amoore in these laboratories.

The organisms are naturally present in the straw or in the dust and they need not be deliberately added. It is, however, important to discover exactly what they use, how they do their work, and what conditions are necessary to their efficiency. These problems are studied in the Bacteriological Department. A new organism has recently been found by Mr. P. H. H. Gray, which not only decomposes cellulose rapidly, but unlike the *Spirochæta Cytophaga* previously isolated in the laboratory, acts in presence of sugar and is indeed stimulated by small quantities of xylose and lignin such as occur in straw. It seems probable that this new organism plays a considerable part in the decomposition of straw in practice, in the making of farmyard manure and other important changes.

PARTIAL STERILISATION AND CONTROL OF SOIL. PESTS AND DISEASE ORGANISMS.

These are conveniently dealt with together. The methods first tested in these laboratories 17 years ago involved either heating the soil or treatment with volatile antiseptics such as toluene and carbon disulphide. The first applications were made in glass houses, and the method first used in practice was heat. This is effective but costly, and it cannot be much cheapened. Chemicals offer much better prospects and search is being made in Mr. Tattersfield's Department for agents which will effect the same purpose as heat at less cost. The obvious method of utilising industrial waste products is less useful than might be expected owing to their variable composition: the first investigation is, therefore, directed to the discovery of the organisms to be put out of action and the testing of chemical compounds in a definite systematic manner, so as to obtain information as to the relationships between chemical constitution and effectiveness. The proper quantity and the suitable time and method of application have all to be determined by direct trial, while laboratory experiments are made to discover more particularly the precise actions going on. The most interesting result thus far obtained is that organic substances, such as the cresols, phenol and cresol derivatives, and the chlornitro derivatives, such as chlorpicrin and chlordinitrobenzene, can, when applied to soil in proper quantity, determine substantial crop increases, though it is not yet known how far the effect is due to removal of disease organisms, and how far to improvement in nitrate production or to direct stimulation of the plant. Under this treatment tomatoes

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under glass gave no less than 5 additional tons of fruit per acre, worth between £250 and £300.

Some of the substances are solids and are easily handled and applied. The significance of the advances made in recent years in these laboratories will be appreciated when it is recalled that the first agents used were highly inflammable substances, difficult and expensive to transport, and that they were applied to the soil at the rate of 10 tons per acre by means of a special injector—another difficult and costly process. These dangerous liquids were soon replaced by a crude cresylic acid (called carbolic acid), an oily liquid watered into the ground at the rate of 2½ tons per acre—but the process was still expensive, the material alone costing over £160, while the labour was considerable. The new substances are solids, and are so potent that 2 cwt. per acre has proved effective. Although they are not as yet on the market, there seems no reason why they should not be made as intermediate products in connection with one of the large organic chemical industries, such as the making of dyes. It is essential to success that the added substances should be removed from the soil as soon as their work is done, otherwise they may injure the plant: this removal is accomplished by a perfectly natural process. Although the compounds are so poisonous to certain undesirable organisms, they serve as food and energy materials to others among the remarkable population of the soil—an illustration from the lowliest type of life of the old adage: " What is one man's meat is another man's poison."

Among the phenol destroying bacteria one has been found by Mr. Gray to possess the interesting property of converting indol into indigo—a change of great biochemical interest.

The laboratory studies of the effects of partial sterilisation on the soil micro-organisms have been continued by Mr. Cutler and Miss Dixon, using heat and phenol as the two agents; application of either results in an increase in the numbers of bacteria and the destruction of active protozoa, but the course of events is not the same in the two cases. Phenol induces rapid multiplication of specialised types of bacteria capable of using it as a source of energy, but the general bacterial population undergoes little change. Moreover, when applied in small quantities, the phenol does not kill the protozoan cysts; these remain dormant until it has disappeared, and then resume their active existence. A temperature of 65° C. causes the complete destruction of protozoa and an initial depression of the bacteria. Subsequently the bacteria increase and attain high numbers which are kept up for long periods.

It has been found that this partial sterilisation effect takes place within relatively short ranges of temperature; 55° C. or less does not bring it about, but 65° C. gives a result as marked as that of higher temperatures. It is worthy of note that 65° C. is the death point for soil protozoa.

An interesting problem has arisen as to the effect of storage of the soil in bottles or open jars on the soil population. When soil is taken from the field, and after sieving placed in bottles, the numbers of both bacteria and protozoa decrease rapidly for the first two or three days, after which there is a slow but steady fall for periods exceeding three months. No explanation can as yet be offered.

Wart Disease of Potatoes.—An important case of control of a soil micro-organism has been investigated by Dr. Brierley, Mr. Crowther, Miss Glynne and Mr. Roach. Wart disease, one of the worst potato troubles in this country, is caused by an organism having a remarkable power of persisting in the soil so that it cannot be eliminated by the ordinary method of ceasing temporarily to grow potatoes. The direct method of studying the effect of various chemicals on the organism is inapplicable owing to the difficulty of germinating the winter sporangia: pot experiments failed owing to difficulties of obtaining infection in pots, till Miss Glynne showed how this could be brought about. Direct field experiments were the only satisfactory method of procedure, and these, while tedious and costly, showed that heat (which owing to obvious practical difficulties was tried only in pot experiments), formaldehyde and sulphur were all effective in dealing with the disease. Heat is too expensive, so also is formaldehyde at present, and possibly for a long time to come, but sulphur is relatively cheap. Mr. Roach overcame the earlier failures by using the Simar cultivator, and so ensuring a better mixture of the sulphur with the soil. There is evidence that on light soils, such as are generally used for potatoes, an application of 12 cwts. per acre of sulphur eliminates wart disease. A large scale trial is now being made to test the practicability and effectiveness of the treatment. Heavier soils apparently require bigger doses of sulphur.

On the other hand, it does not appear that the "scab" of potatoes caused by the fungus *Spongospora subterranea* is amenable to treatment by sulphur, although in America, positive results are said to have been obtained.

INSECTICIDES.

The Staff of the Department of insecticides, fungicides, and partial sterilising agents, under Mr. F. Tattersfield, have for the past three years been engaged in a search for a substitute for nicotine. The seeds and leaves of a tropical plant, *Tephrosia vogelii*, have been found to possess approximately the same toxicity as nicotine; these could readily be obtained should the need arise. Special attention has been directed to the possibility of using synthetic substances, since these can be made to any desired standard of purity, and in any quantity. The work is done on systematic lines, the effects of the various groups being studied as they are substituted in a relatively simple molecule such as benzene. Thus it is found that the introduction of a nitro (NO_2) group into the benzene molecule considerably increases the toxicity, while the methyl (CH_3) group has less effect than any of those tested, the order being :—

$$NO_2 > NH_2 > OH > Cl > CH_3$$

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When two or more groups are introduced into the molecule the toxicity is much affected by their relative positions in the ring (see p. 66). Several of the substances finally obtained are highly toxic both to insects and eggs; some are being tried this year on a field scale.

This investigation, like that on partial sterilisation, raises the important problem of exploiting a laboratory discovery and applying it on the large scale. Between the Rothamsted Station and the agricultural and horticultural industries there is the important difference that the one is working with a few pounds only, while the other may require in the aggregate thousands of tons. It is not possible for the Research Station to bridge this gap, nor to carry up to the farm stage the methods it may evolve. When superphosphate was discovered at Rothamsted many years ago, Lawes completely separated the factory and exploitation sides from the Rothamsted experiments. In a letter to the Ministry of Agriculture, published in the Journal of the Ministry of Agriculture, February, 1922, Lord Elvedon emphasised the lack of bridging agencies, and offered himself to finance a non-profit making syndicate for the exploitation of the "artificial farmyard manure" process (see p. 32). This is proving a very effective way of securing development. Both the insecticide and partial sterilisation work are now almost ripe for extension to the factory, as also is some of the physical work described above. The most suitable procedure has yet to be decided.

PLANT PATHOLOGY.

New laboratories have been erected, to which in September, 1924, the Entomological and Mycological Departments migrated; work is now being done under eminently satisfactory conditions.

In the Entomological Department Dr. Imms has concentrated the attention of the Staff on insecticides, on aphids and on the gout fly of barley. The work on insecticides has already been described (p. 35).

Dr. Davidson's aphid studies have shown the important connection between the nutrition of the host plant and the rate of multiplication of the insects; contrary to general belief, it is the best nourished beans on which the aphids multiply most rapidly.

Certain varieties of field beans are only slightly susceptible to aphid attack, and plant breeding experiments suggest that this factor can be transmitted to new varieties. It appears possible, therefore, that a bean might be evolved of commercial value, and, at the same time, possessing considerable resistance to aphid attack. No rapid progress towards the production of such a variety can be expected owing to the laborious nature of the work and the necessity of making detailed tests at every stage.

A pure line of the bean aphis has been carried on continuously since 1920, over 80 generations having been passed through. The sexual cycle appears with remarkable regularity during early

October in each year. The production of the sexual forms goes on until the following May. If, however, a temperature above 70° F. is maintained, asexual reproduction only occurs, suggesting that the change from the asexual to the sexual method of reproduction is directly influenced by temperature.

The gout fly investigation made by Mr. Frew arose out of a field problem. It was found that couch grass is the chief winter host, and that certain manures, especially farmyard manure and superphosphate, enable the barley plant to escape damage by inducing early growth of the ear out from its ensheathing leaves. Once the plant is infestated, however, nothing can be done : preventive measures only are possible, and of these, early sowing and suitable manuring are the most important.

In the Mycological Department, the chief work has been the study of wart disease in potatoes by Dr. Brierley, Miss Glynne and Mr. Roach, and the commencement of an investigation into mosaic disease of plants by Dr. Henderson Smith. Reference has already been made to the discovery that a dressing of finely powdered sulphur at the rate of 12 cwts. per acre intimately mixed with the soil greatly reduces, and probably eliminates, the disease from light soils. Another practical application of the work results from Miss Glynne's discovering how to infect susceptible varieties with the disease. At present the only method of testing the immunity of new varieties is to grow them for a year or more on badly infected soil. By using Miss Glynne's method described on p. 66 it is possible to discriminate between susceptibles and immunes in a few weeks, a matter of great importance to the plant breeder.

The work on mosaic disease started with the discovery by Dr. Bewley of the Cheshunt Experimental Station of nodules containing certain organisms which appeared on tomato-extract culture-media inoculated with juice of plants suffering from this disease. The work already done indicates that similar nodules may arise on these media when inoculated with other organisms not connected with mosaic disease; but that they also occur readily (perhaps more readily) after inoculation with certain organisms obtained from mosaic-diseased plants. Dr. Henderson Smith is in touch with the members of the Committee on Foot and Mouth disease, there being points of similarity in the two enquiries.

It has already been stated (p. 32) that algae apparently play a part in the highly important nitrogen cycle of the soil; the study of these organisms is carried out in the Mycological Department by Dr. Bristol Roach. The work has necessitated the isolation in pure cultures of a number of species of algae from the soil and the growth of these organisms on artificial media in order to discover some of their physiological properties. Dr. Bristol Roach has been able to show that most algae grow better in presence of small quantities of certain soluble carbon compounds than when they are completely dependent on carbon dioxide in sunlight for their source of carbon; the exact order of preference for these substances varies with the particular species.

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In addition to this qualitative work, Dr. Bristol Roach has introduced exact methods. She has studied quantitatively the growth of a single species in nutrient solutions differing only in the nature of the carbohydrate present, the substances tested being the sugars (pentoses, hexoses, disaccharoses), also mannite and glycerol. The rate of growth of the algae in culture, as measured by the increase in bulk, is constant under uniform favourable conditions for about the first ten days after inoculation, and parallel cultures have equal growth rates within the limits of experimental error. It has therefore been possible to devise a method for growing the alga under constant conditions of temperature, light and aeration, and by taking daily measurements of its bulk to ascertain the rate of growth in the presence of the various compounds under investigation. In this way figures have been obtained for a number of the sugars which can be regarded as representing their relative values as energy sources for the organism concerned. Without this physiological work it is impossible to ascertain with certainty the part played by the algae in the important changes going on in the soil.

STATISTICAL CONTROL OF THE FIELD AND LABORATORY OBSERVATIONS.

It is one of the distinguishing characteristics of the recent Rothamsted work that the field and laboratory observations are, wherever possible, subjected to close scrutiny in the Statistical Department, with the view of estimating the degree of probability attaching to the results, and of indicating modifications in the plan of the experiments that may increase their accuracy. The field data are examined in order to trace correlations between weather, crop growth and other of the quantities measured, the mass of the data being so great that no other procedure gives equally useful results.

As a preliminary, Mr. Fisher found it necessary to develop adequate statistical methods for the study of field data. This work has now progressed considerably.

The methods of experimentation have been closely examined and improvements introduced which allow of a far higher degree of accuracy than could previously be attained.

The difficulties of the older methods of field experimentation arose from uncontrollable variations in the weather and the soil. Experiments repeated on the same soil in different years give discrepant results owing to the variation of the weather; while experiments repeated on different land in the same season give equally discrepant results owing to the variation of the soil. In consequence, even well conducted field experiments suffered from errors of the order of 5 or 10 per cent., a range of inaccuracy too large to meet the requirements of the practical farmer, to whom a difference of 5 per cent. in his average gross yield may make the whole difference between profitable and unprofitable farming. In order to eliminate these errors, three types of procedure have been adopted by experimenters :—

1. To repeat an experiment for a long sequence of years, so that the average yield may be taken to indicate the

result not of a single year's weather, but of the prevailing climate of the district.

2. To repeat the same experiment on a large number of farms, so that the average yield may indicate not the result of a single soil, but the average result of the soils of the region explored.
3. To repeat the same experiments on small plots on an apparently uniform piece of land, and so to obtain some estimate of the experimental errors of field experimentation.

The difficulties encountered by the first method are great expense, delay in arriving at definite conclusions, cumulative effect of soil heterogeneity and uncertainty to what extent the discrepancies between different years are ascribable to weather differences and to what extent to experimental errors.

The difficulties of the second method are expense in the absence of widespread and intelligent support from the farmers, unrepresentative character of the weather of a single season and uncertainty to what extent discrepancies between different farms are ascribable to soil differences, to experimental errors or to weather differences.

The third method possesses the advantage of attempting not merely to " average out," but to evaluate the causes of variation; by itself it makes no attempt to study the variations due to soil and weather, but deliberately aims at evaluating the experimental errors and so of obtaining a result of known accuracy. The principal difficulty encountered has been the marked heterogeneity often found on apparently uniform pieces of land. The soil heterogeneity has often not merely detracted from the accuracy of the results, but has vitiated the estimates of error in such a way that the degree of accuracy of the results is in reality unknown.

These difficulties of the method of experimentation may be overcome by the replication of small plots. A valid estimate of accuracy may be achieved by arranging the plots in the field so that they conform to the requirements of the statistical theory used in the reduction of the data. To this end, definite rules may now be laid down. The lowering of the experimental error may be achieved to a greater extent than has hitherto been attempted by the systematic adoption of the principle of local control, by which plots to be compared are set out on land of comparatively similar quality, without vitiating the estimate of the experimental error calculated from the totality of the results.

Testing these new principles of procedure upon the results of uniformity trials, such as that of Mercer and Hall (1910), it appears that when small plots (1/200th acre) are practicable, the comparative values of, say, five different treatments or varieties may be obtained from an acre of land with errors within 1 per cent., and moreover with known accuracy. The actual arrangement may be varied to meet other requirements, but for small plot work with four, five or six treatments to be

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compared, the Latin Square, replicated and randomised, apparently always gives highly accurate results.

The bearing of this advance on plot experimentation in all its branches is obvious. If plot experiments of known accuracy are repeated either upon different soils or under different weather conditions it becomes possible to distinguish discrepancies due to experimental errors from those due to changed conditions. Where the latter are of importance, it is possible to evaluate them analytically, and the results afford valuable guidance in showing in what soils and in what regions a proposed change in variety, in manurial treatment or in tillage procedure is likely to be beneficial or the reverse. In all cases the need for the very numerous results in order to average out uncontrolled causes of error can be obviated by the use of fewer observations of known accuracy under known conditions.

APICULTURAL INVESTIGATIONS.

Work has been directed towards the solution of two practical problems of importance to beekeepers and is being carried out by Mr. D. M. T. Morland.

(*a*) The suitability of metal " semicomb " in place of wax foundation as a basis for comb building.

The results so far obtained appear to indicate that the metal combs are not suitable for brood rearing in the climate of this country. The Queens did not lay well in them, the brood was scattered and the population consequently not kept up. Moreover, the larvæ tend to leave the metallic cell base and to work upwards towards the wax extension at the mouth of the cell.

Temperature appears to be maintained only at the expense of the consumption of an undue quantity of stores. It is probable that more adequate protection than that afforded by the simple air space of the W.B.C. type of hive is needed when using these combs. It is intended to test this point in the future.

It was also noted that the bees were quick to detect small inaccuracies in manufacture of the artificial cells, and where the cells were on the small side the bees endeavoured to correct matters by missing out a row every now and then and faulty combs were the result.

It was found that a strong stock would store honey in metal combs in the supers. The season of 1924 was, however, such a poor one in this locality that the test cannot be considered as fair.

(*b*) The situation of the frames in relation to the hive front.

The data respecting the situation of the frames in relation to the hive front need to be analysed more fully than at present before reliable conclusions can be drawn. The work has, however, brought to light useful indications for future enquiry.

The chief method in both these investigations has been a consideration of temperature conditions within the hive. It is intended to continue work on these lines and also to make a preliminary study of moisture and carbon dioxide in the hives.

In the summer of 1924 a number of beekeepers representing various county beekeepers' associations met and had a discussion at the Experimental Apiary. During the period under review Mr. Morland has given six lectures and demonstrations before gatherings of beekeepers in various parts of the country.

THE ASSOCIATED FARMS.

WOBURN.

In 1921 the Royal Agricultural Society gave up the Woburn Experimental Farm which they had carried on continuously since 1870, and its two best known fields—Stackyard and Lansome—were in October, 1921, taken over by the Rothamsted Experimental Station so as to ensure the continuance of the permanent wheat and barley experiments which are second only to those of Broadbalk and Hoos fields in point of age. The necessary funds are obtained from a special grant of the Ministry of Agriculture. Dr. Voelcker continues to supervise the experiments as he has done since 1890; the continuity of the records is therefore assured. It should be recorded that he acts in an honorary capacity, freely giving much time and trouble to this work. His report will be found on p. 77.

LEADON COURT.

In December, 1922, E. D. Simon, Esq., then Lord Mayor of Manchester, offered us the use of his farm at Leadon Court, Ledbury, for experimental purposes, himself generously defraying the expenses incurred. It was decided to devote the whole farm to a test of the soiling system of keeping dairy cows, which has aroused much interest among farmers. Small scale trials at the Harper Adams Agricultural College had indicated the feasibility of all the processes involved, but no conclusions as to the economic value of the system could be reached. Mr. J. C. Brown was appointed manager and retained the post till February, 1925, when he was succeeded by Mr. J. H. Hellier.

The farm is 240 acres in extent, there being at present 86 acres of arable and 144 of grass, of which 20 acres will be ploughed out, making altogether 106 acres of arable and 124 of grass: in addition there are 10 acres of wood and waste.

During 1923 and 1924 it maintained a herd of 100 dairy cows and, in addition, some of the young stock and a certain number of pigs. The stocking, however, has proved to be too heavy and some reduction is now being made.

The cropping scheme of the arable land has been as follows:—

	Oct., 1922–Sept., 1923.	Oct., 1923–Sept., 1924.	Oct., 1924–5.
	Acres.	Acres.	Acres.
Mangolds	8	8	8
Marrow stem kale	17	20	16
Mixtures (wheat and peas; rye, beans and peas; beans, peas, wheat, barley	19	35	55
Turnips		9	
Clover, etc.		5	
Wheat	42	9	7
Total	86	86	86

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Of the mixtures part is fed green, part is converted into hay, and part is allowed to ripen, yielding grain and fodder straw. The disadvantage of the cropping of 1924 was that it yielded insufficient straw for fodder and bedding.

The financial returns have been disappointing but it is believed that the initial difficulties are now overcome.

DEMONSTRATIONS AND LECTURES TO FARMERS AND STUDENTS.

The appointment of Mr. H. V. Garner as Guide Demonstrator has made it possible for the Station widely to extend facilities for visiting the plots. Farmers, agricultural students and agricultural workers are cordially invited to Rothamsted at any time convenient to themselves. May and June are good months for seeing the grass plots, July for the cereals, and September and October for the mangolds and potatoes. In the Winter, Mr. Garner is available for giving lectures on the Rothamsted results to Farmers' and Farm Workers' Clubs and similar organisations.