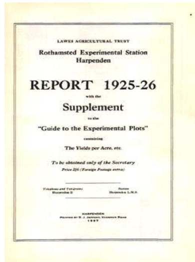
ROTHAMSTED RESEARCH

Report 1925-26 With the Supplement to the Guide to the Experimental Plots


Rothamsted Experimental Station
Harpenden

REPORT 1925-26

Supplement

"Guide to the Experimental Plots"

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Rothamsted Research

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REPORT FOR THE YEARS 1925-26

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 object 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 waste 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; work is now being done to find out as much as possible about it. Three methods are followed:

1. The Rothamsted experiments are repeated year after year on the same lines, and some of them on the same land; the results for the different seasons are then compared by proper statistical methods.

2. Typical experiments are repeated on farms in different parts of the country, the plan being kept uniform so that the results can be compared.

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3. Detailed observations are taken of the rates and habits of growth of crops grown under different treatments. Studies are made of the ways in which these changes affect crop production in different conditions.

Crop production is so ancient an art, and good farming tradition embodies so much wisdom, as science has abundantly proved, that the search for improvement is difficult. The most troublesome problems at the present time are on the arable land; this is proved by the steadiness with which farmers are driven by economic pressure to lay it down to grass. The grassland produces less than the arable, but it involves much less expenditure and offers more possibility of a profit. It is only the ordinary arable culture, however, that is shrinking; intensified culture such as that of potatoes, fruit, vegetables, and the new crop, sugar beet, continues to expand; some of the data are as follows :—

Crops.	Ten Years' Average, 1905–1914.	1924.	1925.
	tons.	tons.	tons.
Intensive Crops, increasing :			
Potatoes	3,614,000	3,541,000	4,209,000
Sugar Beet	—	180,000	440,000
Orchards in Eastern Counties ... acres	51,132	81,136	81,477
Small fruit in Eastern Counties ... acres	40,900	44,329	42,635
Ordinary Cultivation, decreasing :			
Turnips and Swedes ...	21,700,000	18,290,000	16,013,000
Wheat	1,595,000	1,412,000	1,414,000
Hay	8,919,000	8,973,000	7,992,000

Apart from questions of marketing, which lie outside our province, the greatest hope of improving the output from the arable land is to increase the yield for a given amount of expenditure or decrease the expenditure required to obtain the same yield.

FERTILISER INVESTIGATIONS.

One of the easiest ways of achieving these purposes is to make proper use of fertilisers. Nitrogenous manures increase crop yields in almost every season and are the steadiest of all in their action. In the two past years the average increases per acre given by 1 cwt. Sulphate of Ammonia per acre have been :—

	Average up to 1920.	1925.		1926.		
		Rothamsted.	Outside Centres.	Rothamsted.	Outside Centres.	
Potatoes ...	20	22.7	—	25.5	24	cwt.
Barley ...	6.5	6.25	7	Nil	4.5	bushels.
Oats... ...	7	9	3.75	1.80	—	bushels.

The barley and oat results of 1926 are wholly exceptional in our experience, but the 1925 values are very similar to those given in the last Report (1923-24, p. 16). More remarkable still, the results obtained by Lemmermann in Germany are of the same order as ours, showing a similarity of action in spite of the great difference in conditions. The average values he obtains are, per cwt. of Sulphate of Ammonia :—

Potatoes	20 cwt.
Barley	4 cwt. or 8 bushels.

Phosphates and potassic fertilisers have much less regularity of action : they do not always increase every crop, but where they are effective they are of considerable value. Superphosphate is a sound investment for root crops; it may give little return in good seasons when roots are plentiful, but it gives much needed increases in bad seasons when roots are scarce; some of our yields of swedes were, in tons per acre :—

	Poor Year, 1920.	Good Year, 1924.
No artificials	3.3	17.3
No phosphate, but only sulphates of potash and of ammonia	9.3	19.1
Phosphate in addition	16.3	20.6

In like manner potassic fertilisers are an insurance against spring droughts for the potato crop (p. 22). Finally, wherever supplies of farmyard manure are restricted, the fertility of the soil falls off considerably unless phosphatic and potassic fertilisers are periodically added. This is shown in the following yields of barley grown in the same field (Little Hoos), part of which received no phosphate while other plots received periodical dressings of superphosphate :—

	BUSHELS PER ACRE.		
	Phosphate given.	No Phosphate given since 1904.	Falling off in yield.
1909	40.60	36.6	4.0
1914	37.32	23.27	14.0
1922	37.80	20.25	17.5

Much attention has been devoted to these special actions and the investigation has been widened to include other substances affecting the plant besides the fertilisers now recognised.

Recent experiments made in the laboratory and elsewhere have shown that plant growth is affected by three groups of substances :—

1. Those of which the plant is made : the nitrogen, phosphorus, potassium, calcium, sulphur and other familiar constituents of the ordinary artificial fertilisers.

2. Some that help the plant utilise the above constituents, making a slender ration go further, such as sodium, which helps

in the utilisation of potassium, and silicon, which increases the effectiveness of phosphatic and, on some soils, potassic fertilisers.

3. Some necessary to start important processes in the plant, including iron for the formation of green chlorophyll, manganese for essential oxidations, and boron for the normal development of nodules on the roots of beans and certain other leguminous plants; all these are wanted in minute quantities only. Chlorides in larger quantities influence the ripening processes.

Numerous experiments have been made to study this effect of chlorides on the formation of grain in cereals. Barley receiving muriate of ammonia produces a greater number of grains of head corn size than barley receiving the same amount of nitrogen as sulphate of ammonia; the figures are, in millions per acre* :—

	No Nitrogen.	Sulphate of Ammonia.	Muriate of Ammonia.	Excess of Muriate over Sulphate.
1922	17.1	18.9	19.8	0.9
1923	10.5	17.3	18.9	1.6
1924	12.0	16.7	17.0	0.3
1925	12.3	15.1	16.5	1.4

* Obtained by combining the yields with the weight per 1,000 corns.

The increased number is obtained even in 1922 and 1924, when there was little or no difference in weight of the crop. The effect is shown most clearly by muriate of ammonia; it is not so distinct with muriate of potash.

The chloride does not seem to increase the tillering, *i.e.*, the number of heads per plant; its action apparently is to increase the number of grains per head by increasing either the number of florets that become fertile or the number of grains that develop; ordinarily many do not.

Further, the chloride does not increase the total growth of the plant, it only alters the distribution of the plant material, sending more of it to the grain. The non-nitrogenous material seems to be particularly affected, for the grain contains more of it, and a lower percentage of nitrogen, than grain from barley receiving sulphate of ammonia. These effects are well seen in the barley results of 1925 :—

Manure supplied.	Total Produce, lb. per acre.	Grain per acre. lb.	Grain per acre. bushels.	Nitrogen per cent. in dry grain.
No Nitrogen	2,775	1,300	26.0	1.597
Sulphate of Ammonia ...	3,926	1,813	32.25	1.585
Muriate of Ammonia ...	3,932	1,819	35.0	1.552

Other effects quite distinct from these appear to be produced by something associated with cyanamide, on which an extended investigation has been commenced. Usually nitrogenous fertilisers in increasing the yield of grain also increase the length of the straw and so tend to "lay" the crop. In this season's experiments, cyanamide, while increasing the grain as much as sulphate of ammonia, did not cause the straw to grow so long. Further, it caused more tillering, *i.e.*, it increased the number of heads per plant, though it produced no more grain than sulphate of ammonia. It is improbable that the cyanamide itself brings about these effects as it quickly decomposes in the soil; some other substance associated with it is more likely to be the agent.

These results seem to promise a way of obtaining valuable increases in grain crops. For if both the number of heads per plant and the number of grains per head can be increased, the way seems open to considerable increases in yield at only small expense.

Barley.

The amount of barley used for malting is steadily increasing, the fall in the quantity taken by distillers being more than counterbalanced by the increased amount taken by brewers. The figures for the past three years for Great Britain and Northern Ireland have been* :—

Year ended 30th September.	Malt used in Brewing.	Malt used in Distilling.	Total Malt.	Estimated equivalent in Barley of Total Malt.
	cwt.	cwt.	cwt.	cwt.
1923	10,742,000	3,242,502	13,985,302	18,647,000
1924	11,275,235	3,105,525	14,380,760	19,174,000
1925	11,453,591	3,056,601	14,510,192	19,347,000

* Earlier figures are not comparable since they include the whole of Ireland.

Of these quantities it is estimated that 75 per cent. are home grown. It is perhaps too much to hope that all the malting barley could be produced in these islands, but the proportion could be raised with advantage to the British farmer; the maltsters will pay 50/- to 70/- per quarter for barley, which, if kept on the farm and fed to animals, would be no better than grain purchased for 35/- per quarter.

The field experiments have, therefore, been made with malting barley, and their purpose has been to discover the effects of soil, climate and manure on the yield and quality of the grain. They have been carried out under the Research Scheme of the Institute of Brewing, of the Barley Committee of which the Director is Chairman; the arrangement has the great advantage that the produce from each plot is examined in full detail by expert maltsters and brewers.

The first series of experiments, carried out not only at Rothamsted, but on some 15 good barley growing farms in different parts of the country, led to the following conclusions :—

1. Soil and season are the main factors determining yield and quality in barley. Conditions increasing the quantity per acre of non-nitrogenous material (presumably starch) in the grain without correspondingly increasing the amount of nitrogen appear also to be conditions making for malting quality.

2. Sulphate of ammonia in small quantities (1 cwt. per acre) increased the number of tillers and the number bearing

grain; it also increased the yield of grain by about 5 bushels per acre in all the seasons 1922—26, the effect being but little influenced by season. On the average it slightly raised the nitrogen content of the grain, but insufficiently to affect the buyers' valuation.

The Institute of Brewing is going further into the question whether the slight change is of any significance in malting, and for this purpose 30 quarter samples of each experimental lot are being obtained this year.

3. Larger quantities of nitrogenous manure may raise the percentage of nitrogen in the grain so much as to be perceptible by the buyer; in consequence the valuation falls.

4. Superphosphate also increased the number of tillers, but at most centres it had little effect on yield, except in 1925, when it commonly gave increases, and no recognisable effect on quality or on percentage of nitrogen in the grain. On loams in the Eastern Counties, however, it increased the yield and decreased the percentage of nitrogen. In certain circumstances it appeared to decrease the crop.

5. Sulphate of potash caused little or no increase in yield; indeed, at one centre there was a depression. It slightly lowered the percentage of nitrogen in the grain, but had no effect on the weight of 1,000 corns or on valuation.

6. Muriate of ammonia, however, had the remarkable effect of increasing the number of grains of head corn per plant, apparently by increasing the number per head rather than the number of heads. Its action seemed to be to move the material more completely from the rest of the plant to the seed, for it gave no increase in total plant growth per acre (*i.e.*, grain, straw, cavings, and all the rest of the plant). It lowered the nitrogen content of the grain and improved the valuation. A tabulated summary of the Rothamsted results follows :—

Nitrogenous Fertiliser.

	1,000 Corn Weight.		Nitrogen in Dry Matter.	
	No Nitrogen.	Complete.	No Nitrogen.	Complete.
1922	41.8	41.4	1.702	1.767
1923	40.0	40.0	1.617	1.629
1924	39.5	39.1	1.434	1.414
1925	40.0	40.0	1.567	1.649
General Mean ...	40.3	40.1	1.578	1.611

Phosphatic Fertiliser.

	1,000 Corn Weight.		Nitrogen in Dry Matter.	
	No Phosphate.	Complete.	No Phosphate.	Complete.
1922	42.0	41.4	1.760	1.767
1923	39.8	40.0	1.684	1.629
1924	38.9	39.1	1.425	1.414
1925	39.7	40.0	1.636	1.649
General Mean ...	40.0	40.1	1.619	1.611

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Potassic Fertiliser

	1,000 Corn Weight.		Nitrogen in Dry Matter.	
	No Potash.	Complete.	No Potash.	Complete.
1922	41.4	41.4	1.774	1.767
1923	39.7	40.0	1.663	1.629
1924	39.2	39.1	1.451	1.414
1925	39.8	40.0	1.681	1.649
General Mean ...	40.0	40.1	1.641	1.611

POTATOES.

The potato crop is one of the most important in the country; it occupies about half a million acres and forms a large item in the annual value of British agricultural produce. Potatoes are among the few foods of which we produce practically all that we consume.

Potato growing tends to become highly specialised, and, as in all specialised farming, the growers have a thorough knowledge of the peculiarities of the crop. Ordinary field experiments are rarely accurate enough to give them useful information; we have therefore used the new methods, which are not only in themselves more accurate, but permit of the calculation of the degree of trustworthiness of the results.

The purpose of the experiments is to discover

1. the effect of manures on the yield and quality of potatoes;
2. the relation between the amount of fertiliser and the crop yield.

The fertilisers most studied are the nitrogen and potassium compounds, and these necessitate a large number of plots; there have been very few experiments with superphosphate, although it forms the basis of most potato manures.

The nitrogen fertilisers are usually the most consistent in their action, giving every year, with rare exceptions, an increase of about 20 cwts. of potatoes per cwt. of sulphate of ammonia, whatever the season and whether farmyard manure has been given or not. The increases have been, in cwts. of potatoes per cwt. of sulphate of ammonia applied :—

1922.	1923.	1924.	1925.	1926.
20	22—25	20	20	25

The data suggest that potassic fertilisers are a good insurance against loss by spring droughts. On our farm—we have not the necessary data for others—there is curiously little variation from season to season in the maximum yield of potatoes obtainable by appropriate manuring. Our maximum is 11 to 13 tons per acre and the yields of these plots have been between these limits in each of the four years 1923 to 1926 inclusive. Usually 4 cwts. sulphate of ammonia and 4 cwts. sulphate of potash per acre are necessary to secure the maximum crop. Economy of either ammonia or potash reduces the yield, but the effect depends

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on the season; cutting down the ammonia did more harm than cutting down the potash in 1926, but less harm in 1925.

Muriate of potash is cheaper than sulphate of potash and for this reason is used in preference by some growers; it is also put into many potato "compound fertilisers." At Rothamsted it is practically as effective as the sulphate, especially where little or no farmyard manure is given; there is a seasonal factor, and 1923 was especially favourable. The yields have been, in tons per acre :—

	1921.		1922.		1923.		1924.		1925.	1926.
	Farm Yard Manure.	No Farm Yard Manure.	Farm Yard Manure.	No Farm Yard Manure.	Farm Yard Manure.	No Farm Yard Manure.	Farm Yard Manure.	No Farm Yard Manure.	No Farm Yard Manure.	Farm Yard Manure.
No Potash	3.48	1.35	9.03	2.47	11.16	9.72	9.18	6.20	5.03	9.45
Sulphate of Potash ...	3.94	3.76	9.55	8.30	12.45	12.25	8.82	7.28	9.82	11.36
Muriate of Potash ...	3.51	4.12	9.21	8.32	13.28	12.96	8.70	7.15	9.42	11.52
Low Grade Potash Salts ...	3.48	3.55	9.49	8.06	10.48	10.62	9.25	7.85	9.36	10.97

The second cwt. of sulphate of ammonia was more effective than the first in 1926, but less effective in 1923 and 1924; the third and fourth cwts. were less effective than the second, but still profitable. For potassic fertilisers the returns are usually less consistent and they are much affected by the season and by farmyard manure. The crop increases per cwt. sulphate of potash have been in cwts. per acre : —

	1922.	1923.	1924.	1925.	1926.
Rothamsted :					
No dung given	58	25	10	40 to 46	—
Dung given ...	20	10	0	—	20 to 23
Outside Centres :					
No dung given	53	16	—	24	—
Dung given ...	38	25	27	—	13

Farmyard manure reduces the effectiveness of potassic fertilisers by about one-half. Seasonal factors cause even greater fluctuations; 1922, 1925 and 1926 were pre-eminently potash years, 1924 was not; 1923 came in between. The ineffective year, 1924, had a very wet spring; in the effective years the spring was dry. In 1923, the year of intermediate effectiveness, the summer was warm and bright; in 1922, 1925 and 1926, the most effective years, it was cold and wet. The rainfall and sunshine data are :—

Year.	Rainfall.		Hours of Sunshine.		Potassic Fertilisers.
	Spring, May & June.	July–Oct. inclusive.	Spring, May & June.	July–Oct. inclusive.	
1922 ...	2.46	10.13	509	519	Effective.
1925 ...	2.45	13.02	464	544	,,
1926 ...	4.67	7.79	334	578	,,
1923 ...	2.17	12.88	282	768	Less Effective.
1924 ...	6.31	13.66	391	603	Non-Effective.

The effect of manures on quality is difficult to determine. Skilled salesmen have usually been unable to discriminate between potatoes grown with sulphate of potash and those grown with muriate of ammonia or potash. Cooking tests of the 1922 crops were in favour of the sulphate, and there is a common opinion that the sulphate is the better for giving quality.

Chemical examination of the tubers from the various plots has been made each year, but has so far thrown little light on this problem of quality. The percentage of dry matter in the tubers is highest on the unmanured plots; it is lowered by manuring with farmyard manure and still more by adding potassic fertilisers along with the dung. In absence of dung sulphate of potash has usually increased the amount of dry matter while the muriate has decreased it. The proportion of starch in the dry matter is much affected by seasonal factors and no consistent effect of fertilisers can be traced; farmyard manure lowered it in 1922 and 1924, but raised it in 1923, a year when it had but little effect on yield. Potassic fertilisers always increased the percentage of starch in absence of farmyard manure, but somewhat lowered the percentage in presence of farmyard manure; the sulphate was more effective than the muriate in absence of farmyard manure.

The Manuring of Grassland.

The experiments on the manuring of grassland with basic slag have been continued both at Rothamsted and at certain outside centres. Three slags of different solubility were compared on new seeds ley, old hay, and grazing land, sheep being the animals used for grazing.

The results show that solubility is a fairly good criterion of effectiveness; the high soluble slag was better than the medium, and this better than the low soluble. Apparently the difference is not simply in the amount of phosphate present; an increase in the dressing of low soluble slag does not make it equal to the high soluble slag; the two slags behave as if they were different substances. The low soluble slag seems to have distinct value in moist conditions, but not in drier districts.

The experiment on new seeds ley was made at Brooke, near Norwich, and the one on old hay at Enmore, in Somerset; both were by the new methods. The results were, in tons per acre :—

Treatment.	New Hay : Norfolk.		Old Hay : Somerset.	
	Tons per acre.	Per cent.	Tons per acre	Per cent.
No Phosphate	2.28	100	1.37	100
Low Soluble Slag ...	2.28	100	1.49	109
Medium Soluble Slag ...	2.31	101	1.59	116
High Soluble Slag ...	2.65	116	1.53	112
Standard Error ...	—	5.4	—	7.1

The grazing experiments are more difficult to carry out, and the new methods cannot be used owing to the great difficulty of setting up an adequate number of replicate plots. The liability to error is increased by the irregularities of the pasture, the inequalities among the sheep, and the fact that the land must be very closely grazed or the herbage becomes too coarse to nourish the sheep. This close grazing is very important; at one centre the sheep did worse on the slagged land than on the unmanured, simply because the grass grew too much for them. In consequence the grazing results are not as sharp as those on arable or hay land, where the errors are much smaller.

The Rothamsted grazing plots, which were set up in 1921, were re-dressed with similar slags in 1925. During the whole six years neither the Gafsa nor the low soluble slag had any action; the high soluble slag acted better. For these high soluble slags, however, their order of efficiency was not the same as the order of solubility. The results were :—

Average Yearly Live Weight Increase in Sheep. lb. per acre.

Description of Phosphate.	Composition.		Rothamsted Average for		Thrussington Average for 2 years, 1925–26.
	Total Phosphate.	Solubility.	4 years, 1922–25.	2 years, 1925–26.	
No Phosphate ...	—	—	124	149	170
Gafsa	—	—	123	151	185
Slag, Low Soluble ...	21.1	27.7	127	146	209
High Soluble ...	19.8	70.9	159	180	181
High Soluble ...	19.8	70.9	146	147	187
High Soluble ...	42.5	77.2	120	150	—
High Soluble ...	18.0	81.3	106	138	216
No Phosphate ...	—	—	107	136	—

Comparison of the Rothamsted results with those obtained elsewhere brings out the very interesting fact that grassland is not readily improved by slag if an acre of it yields some 200 lbs. live weight increase in sheep. The striking results are obtained on land giving only 50 or less lbs. increase per acre. The figures are :—

Centre.	Live Weight Increase, lb. per acre.				Number of Sheep carried per acre.			
	1925.		1926.		1925.		1926.	
	No Manure.	High Soluble Slag.	No Manure.	High Soluble Slag.	No Manure.	High Soluble Slag.	No Manure.	High Soluble Slag.
Fiddington ...	242	212	187	93	6.5	6.5	6.3	6.3
Thrussington ...	134	165	156	225	3.7	3.7	6.0	6.0
Rothamsted ...	81	103	190	196	6.6	6.6	6.1	6.1
Hebron ...	53	123	18	71	2.0	4.0	2.0	4.0

Fertiliser Action and the Law of Diminishing Returns.

Periodically a good deal is heard about the Law of Diminishing Returns, and farmers are reminded that the use of fertilisers, or any other improving agents, beyond a certain point is not economically sound, the extra yield obtained not paying the additional

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cost of winning the crop. This is undoubtedly true, but it is also true that many farmers are not near the point of diminishing returns and would obtain better results, both in output and financially, by putting more into the land.

Data are accumulating (see 1923-24 Report, p. 16) to show that in many instances the return from fertilisers and other improvements increases with increasing quantities before it begins to decrease. This is shown in the potato experiment of 1926, where the successive increases in yield given by successive doses of sulphate of ammonia are, in cwts. per acre :—

Quantity of Sulphate of Potash per acre.	Successive Increases in yield for Sulphate of Ammonia. 1st cwt.	2nd cwt.	3rd and 4th cwt.
1 cwt.	23.6	31.6	6
2 cwt.	23.2	22.6	13.2
4 cwt.	24.4	28.6	19.0
Mean	23.7	27.6	—

The second cwt. of sulphate of ammonia is not only profitable, but more profitable than the first.

This increasing return has so far been observed only with nitrogenous manures, and it is marked only in certain seasons. It may, however, always occur but be missed : in a field experiment only few quantities can be tested, and usually for potatoes the steps have been greater than 1 cwt. per acre.

The effect of the fertiliser is influenced by the time at which it is applied. In the experiments on oats in 1925 the late dressing gave the better result for 1 cwt. sulphate of ammonia, while in 1923 the earlier dressing had proved the better. In both years 2 cwts. per acre gave better returns when applied late. The increased yields for the early applications of the sulphate of ammonia are curiously similar : there is more difference for the late application :—

Time of Application.	1923. 1 cwt. bush.	1923. 2 cwt. bush.	1925. 1 cwt. bush.	1925. 2 cwt. bush.
Early (*a*)	8.1	17.3	9.8	16.8
Late (*b*)	5.4	24.5	14.7	19.7

(*a*) March 28th in 1923, March 5th in 1925.
(*b*) May 22nd in 1923, May 5th in 1925.

The effectiveness of the late dressing is probably in some way bound up with the relation between grain formation and growth.

METHODS OF FIELD EXPERIMENTATION.

The foregoing pages show how completely the modern fertiliser problems differ from those of the earlier days. Formerly the interest lay in showing that good crops could be obtained by the use of artificial manures, or in comparing artificials with farmyard manure. The results have now become embodied in general farming experience and no longer form the theme for experiments. Modern problems are concerned much more with matters of detail: such as the comparison of fertilisers which are nearly alike, or the tracing out of the effects on the growing crop and seeing how these can be used for increasing the output from the farm. Greater accuracy is now necessary than formerly, because a five or ten per cent. margin may make all the difference between profit and loss to the farmer: the results must also be obtained quickly, before changes in the economic situation have destroyed the interest in the work.

This change in the problems has necessitated a change in the method of making field experiments. The older methods had the great merits of directness and simplicity, but they are not very accurate; however carefully carried out, they are liable to errors which in any year may amount to at least ten per cent. Improvements in technique have reduced this liability, and repetition of the experiments for a number of years, as at Rothamsted, tends to cancel out some of the errors. But quite apart from the fact that agriculturists now want information speedily, there is the serious disadvantage that the amount of the error is unknown. For any valid estimate of error it is essential that the arrangement or the "sample" should be at random and not the result of selection, which forms the basis of all the older methods.

The statistical and field departments have worked out new methods which are not only more accurate in their working details than the old ones, but satisfy this statistical requirement of random sampling as against selection, and thus admit of the calculation of the error, so that the experimenter knows what degree of significance attaches to the results. Further, the experimenter can adjust the degree of accuracy to the requirements of the problem; if he needs an accuracy of two per cent. he can get it; if, on the other hand, he needs only to be within 10 per cent., he can change the design accordingly. The higher the accuracy aimed at, the greater the elaboration and the cost, and although it is possible to interweave various experiments into one large whole, nevertheless, the cost necessarily remains high.

These new methods are now used for all the new experiments (though not for the classical ones, which are still continued in the old way without change) and the standard error is calculated and recorded in the tables. This is the first time our field experiments have been treated in this way. (See p. 122.)

The new methods are the outcome of long previous investigations in which several workers, including the agriculturist, the ecologist, the plant physiologist and the statistician took part.

It was recognised that in the past more useful information had often been obtained from field observations during the growth of the crops than from the final weighings at the end. A field laboratory was therefore built on the experimental fields and equipped with appliances for making measurements on the growing plant, and an ecologist (T. Eden) and a plant physiologist (E. J. Maskell) devoted their whole time to measuring and observing such things as rate of growth; for cereals the number of tillers, dates of emergence of heads, length of straw and of ear, number of grains per ear; for roots and potatoes height and spread of the plant, nature of foliage, etc. These observations

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promise to be of great value in explaining the effect of soil and season on plant growth and on fertiliser action.

The figures for final yield, however, must always be the chief, and have often been the only, test of any agricultural treatment. In order to increase their value a statistical investigation was undertaken to discover the basis on which improvement could be effected, and field experiments were used to test which of the various theoretically sound methods were also practically sound.

The work began in 1919, when Dr. Fisher applied to the study of variation an arithmetical analysis known as the analysis of variance, which had the advantage over the ordinary calculus of correlations of avoiding both the calculation of a large number of irrelevant values and also the numerous corrections to which correlations are liable, especially with small samples. He applied the method to the Broadbalk wheat yields and showed its value for measuring the effect of distinct groups of causes. This investigation, however, showed the need for more exact methods than those previously used for treating the small number of cases, or samples, generally available in agricultural investigations. The first example of an analysis of variance in its modern form was the examination of the results of T. Eden's experiment in 1922 on the response of different potato varieties to manures (Fisher & Mackenzie, Journ. Agric. Sci., 1923). Somewhat later, " Student " gave alternative proofs by himself and by Fisher of formulæ appropriate to cereal variety experiments. Thus rigorous methods of statistical examination were elaborated.

The next step was to develop a correspondingly rigorous field technique, and this was done by Dr. Fisher in co-operation with T. Eden and E. J. Maskell. The chief difficulty was to overcome the effects of the irregularities in the soil which had long been a serious stumbling block to field experimenters.

Part of the irregularity or heterogeneity could be eliminated by suitable arrangements of the plots, but there was always an unknown remainder of residual errors. It was shown that the statistical analysis previously developed could eliminate the former and at the same time afford a valid estimate of the remaining errors, provided that the plots were sufficiently replicated and deliberately randomised.

Dr. Fisher then devised various types of experiments to meet the requirements of the statistical analysis and tested these on the results of uniformity trials so as to discover which were the most accurate and convenient in actual working. Two types stood out as satisfactory; randomised blocks and Latin squares. The randomised block is the simpler and the more easily adjusted to suit the peculiarities of the field and the crop. The experimental area is divided into several strips or blocks, each of which contains one plot of each treatment, the arrangement being deliberately at random and determined not by selection, but by writing the possible arrangements on separate cards, shuffling them, and drawing one out. Since one block is not directly compared with another, the differences in soil fertility between them are eliminated; and since the arrangement within the blocks has been entirely at random, the significance of the results can be estimated. An example of this method is given on p. 146.

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The Latin square is the more accurate but less widely applicable in fertiliser experiments. The plots are arranged with as many rows and columns as there are treatments. Each treatment appears once, and only once, in each row and each column. A surprisingly large number of arrangements are possible, but the selection is again deliberately at random and, as before, is effected by the shuffling and drawing of cards. The potassic fertiliser experiments on potatoes are an example (p. 138).

Two years' experience of these methods has satisfied us that they are practicable, though they are costly because they necessitate large numbers of plots : a single experiment may require some 50 to 80 plots. The additional accuracy, as compared with the older methods, is a great boon to the agricultural expert because it gives him much better material on which to base his advice to farmers. And it has the supreme advantage that the actual figures of crop yield have for the first time become definite scientific data, so that they can be related to other values such, for example, as meteorological data. Strict comparison can be made where previously only vague and general comparisons were possible.

THE INFLUENCE OF WEATHER ON CROP YIELDS AND FERTILISER ACTION.

The new methods outlined above for making field experiments, and studying the results, make it possible to discover with considerable precision the influence on crop yields of rain, temperature, sunshine, or any other meteorological factor that can be measured and expressed in figures. Dr. Fisher has already traced the connection between rainfall in the different months of the year and wheat yields under different fertiliser treatments : a similar investigation into barley yields has now been made. The effect of hours of sunshine on wheat yields has also been examined : the most striking effect is of autumn sunshine just before or just after the sowing of the crop : whether the benefit arises from the warming or the drying of the soil is not yet found. For the rest of the year, even in July, actual sunshine seems unimportant : the great weather factors seem to be the temperature and the rainfall.

Observation in the field has brought out several interesting facts : that nitrogenous fertilisers are affected less than any others by season (p. 17), that phosphates act better on swedes and turnips in a cold, wet year than in a good growing season (p. 18), that potassic fertilisers act better on potatoes in a dry spring than a wet one (p. 23). With fuller knowledge of these actions it would be possible to draw up schemes of manuring suitable to any specified kind of season. To some extent this has been done for potatoes. There are each year at Rothamsted a number of plots of potatoes receiving various manures. The highest yield shows little variation from year to year, being about 12 tons per acre whatever the season (excepting in 1921, the summer of exceptional drought). But the manurial treatment required to get it does vary : in some seasons potassic manures were the most important, and in others nitrogenous.

THE USE OF LIME AND LIMESTONE.

Lime and limestone have two important effects upon the soil, both of which have been studied in considerable detail.

1. On all soils they neutralise acids and thus change sour or acid soils to a sweet or neutral condition.

2. On heavy soils they improve the texture of the clay, reducing its stickiness and so facilitating the movement of the implements, the soaking away of water and the growth of plant roots, especially on arable soils.

It is usual to measure the intensity of the acidity on the so-called pH scale on which 7 stands for neutrality, higher numbers for alkalinity and lower ones for acidity. Ordinary good soils have values of 7 and over; alkaline soils do not occur in this country, but of the many acid soils examined, very few have values as low as 4; most of the bad ones are about 5 and the somewhat acid ones about 6.

Dr. E. M. Crowther has investigated various methods for measuring soil acidity and for calculating the amount of lime necessary to reduce it to any desired extent.

As a general rule neutral soils are the most fertile. It is not always necessary, however, to aim at complete neutrality. Some crops will tolerate a certain amount of acidity and do not respond to lime added beyond this joint. Potatoes grow just as well on acid soils of pH 6 as on neutral soils of pH 7, and they are less liable to scab; addition of lime is therefore waste of money. Lucerne, on the other hand, has failed on soils with pH 6. Certain plant disease organisms flourish in acid conditions; finger and toe becomes serious when the acidity is worse than pH 6. Some of Dr. Crowther's measurements are :—

pH Values for Pairs of Comparable Soils Differing in Agricultural Value.

Centre.	Crop.	Condition.	pH.	Condition.	pH.
1. Rothamsted...	Swedes...	Finger and toe	5.85	No finger and toe	7.90
,,	,,	,, ,,	6.05	,, ,,	7.87
2. Garforth ...	,,	,, ,,	5.66	,, ,,	6.13
3. Aberdeen ...	Turnips	Much finger and toe	6.21	Little finger and toe	7.13
4. Somerset ...	Barley ...	Failure ...	4.41	Good ...	5.77
5. Ipswich ...	Lucerne	,,	6.15	,, ...	7.86
6. Carrington Moss	—	Waste land ...	3.01	Cultivated ...	5.52
,, ,,	—	Bad field ...	4.88	Good field ...	5.14
7. Pusey ...	Potatoes	Much scab ...	7.40	Little scab ...	6.13
,, ...	,,	,, ...	7.65	,, ,,	6.75

Much work has been done to discover the limits of tolerance of the most important crops. The list as it stands at present, beginning with those that cannot tolerate acidity and ending with those that can stand a good deal of acidity, is :—

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Less Tolerant.	More Tolerant.
Red Clover. Foxtail (*Alopecurus pratensis*). Barley. Peas, beans and vetches. Wheat Mangolds. Mustard. Rye Grass. White Clover.	Cabbage and kale. Lupins. Alsyke. Swedes. Oats. Cocksfoot. Potatoes. Rye. Sweet Vernal Grass. (*Anthoxanthum*). Sheep's Fescue. Yorkshire Fog (*Holcus lanatus*). Sorrel (*Rumex acetosa*). Rhubarb.

The practical outcome of this work is that it enables the expert to advise the farmer:

1. Whether his soil reaction is suited to a particular crop and if not how much lime should be added to make it suitable;

2. What crops can be grown on the soil as it is or as it would become with small and inexpensive additions of lime.

CULTIVATION.

The greatest single item of cost in arable husbandry is the cultivation of the land, and this has been so fully developed as an art by farmers and implement makers that little further development can be expected on empirical lines. Few cultivation experiments have been made and farmers visiting experimental farms are rarely shown anything bearing on the subject. The reason is that no underlying science of cultivation has yet been developed corresponding with the science of manuring, nor could it have been done until the physical properties of the soil were better understood. In recent years important advances have been made in the Soil Physics Department under Dr. Keen, and the extension of the work to cultivation problems has followed automatically.

The work falls into two chief divisions: investigations and comparisons of cultivation processes; and studies to ascertain how cultivation affects the soil. In both divisions detailed examination is made whenever possible of the growth and final yield of the crop.

During the past year three different methods of producing a seed-bed for roots (swedes) have been compared: rotary cultivation, on the ridge, and on the flat. Soil measurements made immediately before and during the operations showed that the main result of rotary cultivation was to produce a much softer tilth, which was well loosened or puffed up by the action of the tines. The percentage of finest soil crumbs was no greater than on the ridged plots, and but little greater than with the flat cultivation, but there was a marked reduction in the percentage of the large lumps of soil. These differences were reflected in the earlier germination and better first growth on the rotary cultivation plots. Later on the deep uniform tilth proved detrimental, for the soil hardened, or "panned" to a greater depth than on the other plots. Growth was checked, and well before harvest it was obvious that the yield from the rotary cultivation plots would fall greatly behind the others. These main comparisons have been supplemented by many soil, plant and meteorological measurements; the full interpretation must be deferred until several years' data have been obtained. Broadly speaking, the effects of cultivation are three :—formation of tilth, control of air and water supply to the roots, and suppression of weeds. The weed problem is very important in normal years, and when opportunities for cultivation are restricted by wet and mild winters, it becomes exceedingly acute, especially on heavy land. The number of weed seeds capable of development in these conditions is very large; it becomes enormous on certain of our experimental plots where wheat is grown year after year, and opportunities for adequate cultivation are restricted. Dr. Brenchley estimates that one of our fields contains in places no fewer than 100 million good poppy seeds per acre, to say nothing of other kinds of weeds. Fortunately, young plants are as a rule easily killed by appropriate cultivation, and this is one of the chief benefits it confers on the land.

The study of the cultivation processes is much facilitated by measuring the resistance offered by the soil to the passage of the implement : this is done by means of a dynamometer inserted in the hitch between the implement and the tractive force. The records are of direct use in comparing the working efficiency of different implements, provided the heterogeneity of the soil itself is previously ascertained and allowed for. The records are also of further value after analysis in the laboratory, in ascertaining the part played by soil cohesion and plasticity, surface friction, etc.

The dynamometer measurements thus form an essential connecting link between field and laboratory studies, and it is necessary that the instrument itself should be as reliable as possible. Much time has been given to the development of a new design, and an instrument has now been evolved which has satisfactorily passed severe and extended tests. It has been built up partly from stock-pattern apparatus already on the market, while the remaining portions were developed in our own workshop, thus avoiding the costly process of empirical trial and adjustment. The instrument is very light and convenient in use, and as the record is obtained on a moving celluloid strip, it is grease and weather proof. Every range in draught from a few pounds to several tons can be recorded. The apparatus has been placed on the market by the Cambridge Instrument Company.

The heterogeneity of soil that may appear quite uniform to the eye is brought out by the "isodyne" maps of the field, all points having the same soil resistance being joined by a smooth continuous line. These maps, which resemble the familiar contour maps, are readily constructed in the laboratory from the dynamometer results. (See 1923-24 Report, p. 29.) The annual tests of the past five years on Broadbalk gave strong evidence that the distribution of the soil heterogeneity across an area remained sensibly constant from year to year, *i.e.*, the isodyne maps for successive years are all much the same. In the past season a crucial test of this constancy has been made on another field, in which every factor—except the soil itself—was changed from the previous years' tests : the new dynamometer was used instead of the old one, quite different ploughs were employed, horses were substituted for the tractor, with a corresponding reduction in speed, the direction of ploughing was across the field and not along it, and the season was spring instead of autumn. In spite of these very different experimental conditions, the two isodyne maps were similar.

Although the distribution of the differences in soil resistance from place to place remains unaltered, the average absolute values differ from year to year. The full reasons for this have still to be found. Moisture content has little effect, and laboratory investigations show that the changes in the colloidal condition of the clay from one season to another, are most likely to be responsible. These are, to some extent, under the farmer's control. Additions of farmyard manure or of chalk reduce the drawbar pull considerably, so much indeed as to effect very appreciable reductions in the cost of the operation. Some of our results have been given in previous Reports; recently further investigations of the effect of chalk have been made. In these experiments the soil had been chalked in 1912 at the rate of 15 tons per acre by the old Hertfordshire method. The isodyne map of the field shown in Figure I is

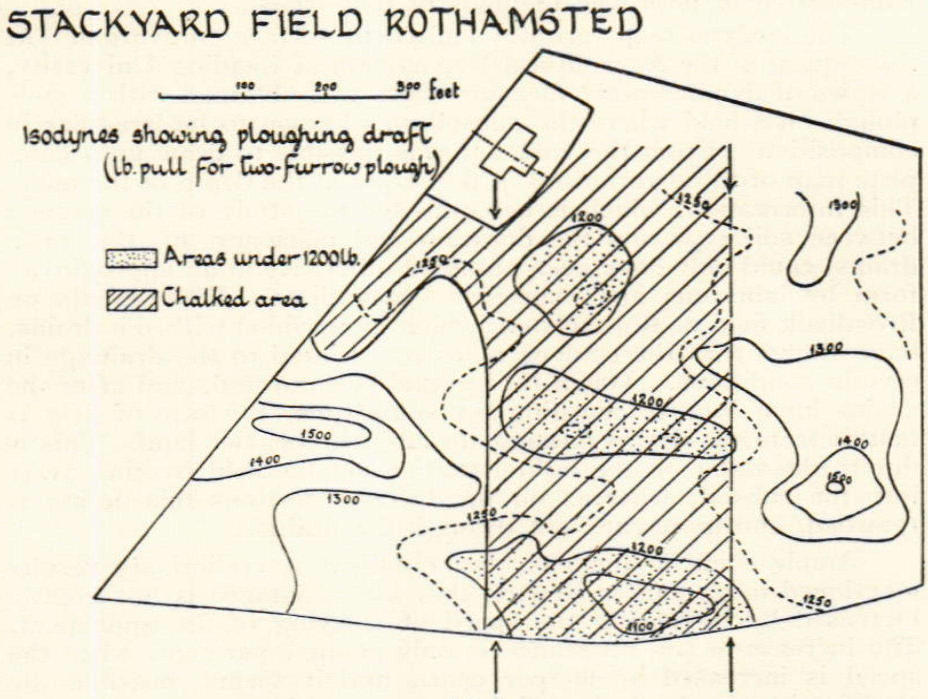

FIG. I

obtained from the 1925 ploughing results. It will be seen how persistent is the advantage, the resistance on the chalked area being much below that of the flanking unchalked strips. The method is feasible only on soils overlying the chalk, and in any case, the first cost is now too heavy. Farmers are therefore more and more relying upon purchased lime or ground limestone, both of which are applied in much smaller quantities. While these

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modern dressings correct sourness, it is not known how far they help to reduce the labour of cultivation. Experiments will be made this year with the aid of grants from some of the associations of limestone firms.

The dynamometer measurements have other applications in addition to the uses detailed above. They constitute at present the best single value specifying the condition of the soil in the field; no other analytical method yet devised could give such detailed data without a prohibitive expenditure of time and energy.

The condition of the soil as reflected by the isodyne maps is closely related to the early stages of plant growth. The number of wheat plants surviving the winter, and the percentage of tillering, are found to be greatest on the areas of low drawbar pull. The isodyne maps do not represent the variations in final yields of wheat, however, as the fewer survivors on the heavier land have a better chance of development, and may ultimately make up in numbers of mature ears what was lost in number of plants. On the other hand, the yield of swedes does appear to be related to the distribution of the isodynes. Although this work is still in its early stages, and the degree to which the relationships are altered by seasonal factors has still to be ascertained the results have already been of value in the development at Rothamsted of improved methods of plot trials.

The isodyne maps are not limited to surface cultivation. At the request of the Agricultural Department of Reading University, a series of dynamometer measurements was obtained with a mole plough on a field where the subsoil was known to be irregular in composition. From the values it was possible to draw up a complete map of these variations in the strata at the depth of the mole. This information, which is essential for the study of the relation between soil type and the duration and efficiency of the mole drains, could only have been obtained otherwise in an approximate form by laborious and expensive excavations. Experiments on Broadbalk field at Rothamsted, which is provided with tile drains, have shown that the isodyne maps are related to the drainage in certain conditions. When the ground is saturated, and after the drains have been discharging for some time, the rate of flow is fastest from the drains passing through the heavier land. This is due to the water on the lighter portions of the field soaking away into the subsoil, whereas on the heavier portions this action is retarded, and more runs out through the drains.

Ample confirmation has been obtained of preliminary results mentioned in an earlier Report, that soil resistance is not greatly increased by increasing the speed of working of the implement. The increase in soil resistance is only about 7 per cent. when the speed is increased by 60 per cent., and it seems possible by modifications in the design of the tractor and implements to hasten considerably the work of cultivation, thereby saving money, time and much future trouble, especially in difficult seasons.

Laboratory experiments show that the drawbar pull is not a simple quantity, but is made up of a number of factors which must be analysed before the field results can be interpreted. Three factors have been studied in detail by Dr. Haines: the friction between the surface of the implement and the soil, the cohesion of the soil and its plasticity. These are all much affected by water content, but in different ways; the cohesion decreases but the friction increases as the water increases; the effects just about balance, so that the drawbar pull, the sum of all of them, alters but little.

This analysis is being continued in order to insure a better understanding of the field experiments.

The work on soil cultivation is beginning to afford a physical explanation of the "condition" of the land—a term much used by farmers. It has also aroused much interest among the implement manufacturers, who are endeavouring, through their Association, to find part of the necessary funds to ensure the continuation and adequate development of this subject at Rothamsted.

GENERAL SOIL PHYSICS.

Much of the work in the Soil Physics Department is necessarily concerned with the general development of Soil Physics, the science that underlies soil management and explains the air, temperature and water relationships of soils.

Many attempts have been made to find means of expressing the highly complex water relationships. They appear to be best expressed by such properties as cohesion, plasticity and shrinkage, which show variations at moisture contents where plant growth is satisfactory; the vapour pressure method that at first sight seems more promising, is not so satisfactory since the values are still at their maximum when the moisture content is well below the minimum for plant life.

The vapour pressure curves, however, promise to be important in soil physics; they show typical hysteresis effects associated with colloids, and they are markedly affected by treating the soil with agents known to disintegrate the aggregates characteristic of good tilth. They are also of use in the search for a " single value " measurement for classifying soils—a long sought end—to which much attention has been given in the Physics Department.

Hitherto it has been difficult to decide what property, or combination of properties, the " single values " proposed really measure. Many of them have been tested on some forty different types of soil. The air-dry moisture content, or, more accurately, the moisture content at 50 per cent. relative humidity, as given by the vapour pressure curve, was found to be controlled mainly by the percentage of clay in the soil; while the " sticky point " (the water content of a plastic mass of soil when it first ceases to adhere to the fingers) is controlled by the material lost on ignition of the soil, i.e., the organic matter and water of constitution in the clay. These discoveries have greatly simplified the problem of " single value " classification.

The cohesion of soil presents an interesting problem. The work of Atterberg, in Sweden, appeared to show that, although the cohesion decreased with increasing moisture content, the curve connecting the values was broken into two distinct portions.

Atterberg considered that soils could be classified by measuring the moisture content at which the break occurred. We have not been able to reproduce these results at Rothamsted, our curves being always smooth and unbroken within the limits of experimental error. Dr. Haines has now shown both theoretically and experimentally, that the capillary effects of water in the pores of a soil block give rise to cohesion values that increase to a maximum at the highest moisture content the soil block can hold before it becomes disintegrated. This suggests that the two sections of Atterberg's curve may be attributed to two types of cohesion, one predominating at high moisture content and due to capillary forces, and the other predominating at low moisture contents and due to the colloidal nature of the soil. The features of these two factors are such that, when combined, a broken curve might be expected with certain types of soil. Quantities of the colloidal material have been obtained by means of the Super-centrifuge in order that its properties and its effects on the soil may be studied.

Dr. Keen has acted as convener of a committee, including Professors Comber of Leeds, Hendrick of Aberdeen and Robinson of Bangor, appointed by the Agricultural Education Association to investigate methods of mechanical analysis of soil, it being now known that the old method used for over twenty years in this country is untrustworthy, since it fails to secure complete disintegration of the soil crumbs. After full tests at Rothamsted and elsewhere, Professor Robinson's method has been officially adopted, and the more important of the older analyses will now be revised.

A measure of soil tilth has been obtained by studying the degree of disintegration secured under standardised laboratory conditions on soil brought in from the field.

Work in the Empire.

The water relationships of the soil, important as they are in British farming, are of supreme importance for great parts of the Empire where low rainfall compels recourse to irrigation for crop production. An increasing number of problems is being referred to Rothamsted from various regions of the Empire, and agricultural experts have been sent from India and Africa to study methods and problems in our laboratories.

The Empire Cotton Growing Corporation has made provision for a soil physicist to carry out investigations at Rothamsted. Dr. E. M. Crowther, who holds this post, last year studied some of the soil problems of the Gezira, the great irrigated area between the White and Blue Niles, for which purpose he worked in the laboratories at Wad Medani for the six months, October, 1925, to March, 1926. (See Paper No. xxxiii, p. 67.) He succeeded in tracing relationships between early rainfall and crop yields and between permeability of the soil and its fertility, a rapid rate of movement of water being associated with a low salt content and high fertility. Some of the problems have been brought back to the Rothamsted Laboratories for further investigation.

SOIL MICROBIOLOGY.

Large as are the quantities of artificial fertilisers used in this country, the amounts of organic manure, such as farmyard manure, animal excretions, green manure, or residues of clover, or seeds leys are much greater. It has been estimated that farmers of this country make farmyard manure of the value of £14,000,000 a year, to say nothing of the value of the clover and other residues ploughed in.

These materials are not in themselves of use as fertilisers. It is only when they have undergone certain changes that they become valuable. During the process they may and often do suffer serious losses; it is estimated, for example, that about half the value of the farmyard manure is lost. These changes, both beneficial and harmful, are brought about by minute organisms living in the soil.

Soil micro-organisms thus play an important part in soil fertility. Among the more important are the following:—

1. They decompose the residues of plants and animals, converting them into simpler substances, such as nitrate, potassium, calcium, and other compounds that serve as plant nutrients, and also producing humus, which greatly improves the soil. The decomposition of cellulose can be effected both by fungi and bacteria. During the past year Dr. Kalnins has found several new bacteria capable of decomposing it aerobically, while Dr. Rege has isolated three common soil fungi which, under aerobic conditions are, in combination, as active as the total soil population and far more active than the soil bacteria alone. No soil organism, however, either fungus or bacterium, has yet been found to decompose lignin, which, on chemical grounds, is now regarded as a probable source of humus.

2. The carbon dioxide produced in the decomposition and during the respiration of the organisms, partly remains in the soil, dissolving certain soil constituents, and thus influencing the supply of mineral substances to the plant; the rest escapes into the air, where it contributes to the supply of carbon for the plant.

Measurements have been begun of the amount thus escaping from soils under different manurial treatments.

3. Certain substances formed in soil and harmful to growing plants are decomposed and rendered innocuous by some of the organisms. The decomposition of phenol was dealt with in the last Report; that of indol, a well-known product of the bacterial decomposition of organic matter, has been studied this season. Three soil bacteria found by Mr. Gray have the remarkable power of converting it into indigo. This reaction does not furnish the organisms with all the energy they need, so that some other carbon compound has to be present as well.

4. A few of the soil organisms fix gaseous nitrogen from the air, converting it into protein, which is readily broken down to ammonia, and appears ultimately as nitrate.

5. Most of them, however, obtain their nitrogen from nitrogenous compounds in the soil. Many assimilate nitrate, thus competing with and injuring the plant in spring and early summer. In late autumn and winter, however, the plant does not suffer and the soil gains because the nitrate which they take is converted into

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protein, and thus protected from being washed out from the soil; in the following spring the protein decomposes with formation of nitrate once more.

The organisms most directly concerned are bacteria which bring about all these changes, and fungi and algæ which effect some of them. Of the protozoa, the amœbæ, some of the flagellates and, so far as they are active, the ciliates, are indirectly important because they keep down the numbers of bacteria. The action of the rest of the flagellates, which occur in large numbers, is unknown, but all the protozoa, like the fungi, algæ, and bacteria, lock up in their bodies nitrogen compounds which, if not so held, might decompose and be lost from the soil.

The study of soil micro-organisms has for many years been one of the characteristic features of the Rothamsted investigations and post-graduate students come from all parts of the world to take part in the work.

It has been shown that the common bacteria, protozoa, algæ and fungi, are widely distributed, occurring in the soils of widely separated regions, there being apparently less variation in the soil population than in the surface flora or fauna. The numbers of the bacteria* and the protozoa in field soils can be estimated; they are very great, but not steady; they fluctuate continuously, and the fluctuations on adjoining plots of land are similar, though they are not obviously related to changes in soil moisture and temperature. The numbers of bacteria and active amœbæ, however, change in opposite directions; when the active amœbæ increase the bacteria decrease and *vice versa*; this happens both in the field and in laboratory tests where sterile soils are innoculated with various groups of organisms. While the protozoa reduce the numbers of bacteria it is not yet clear how they affect the changes produced in the soil. This year's work by Mr. Cutler and Miss Crump suggests that amœbæ, the flagellate *Cercomonas crassicauda,* diminish the evolution of carbon dioxide from soil and hinder the decomposition of added organic matter (*e.g.*, sugar), which suggests that they may decrease the amount of decomposition of plant and animal residues, though the action is not entirely simple. Dr. Skinner confirmed these observations, using soils partially sterilised by heat, and showed also a decrease in ammonia production. But protozoa increase the amount of nitrogen fixed by Azotobacter, an apparent anomaly which Mr. Cutler explains as the result of the amœbæ feeding on the Azotobacter, and so conserving in their bodies much of the nitrogen already fixed and also maintaining a high efficiency of fixation by keeping the cultures young. This reaction does not stand by itself, since the nitrogen fixing organisms appear generally to work better in company than alone.

Mr. Sandon's systematic examination of the soil protozoa has revealed about 250 different forms; a description and key to their classification has been prepared. (See p. 88.) Most of these are also found in other habitats, but 18 of them, 8 flagellates and 10 amœbæ, have so far been found only in soil.

*Not the total numbers, for no medium allows the development of all the bacteria present in soil. The estimates are, however, comparable with one another.

The soil algæ are studied by Dr. B. M. Bristol Roach. Those which are on the surface in full light obtain their energy and their food from sunlight and carbon dioxide like other green plants; they add to the stock of organic matter in soil. Those which are buried in the soil and so cut off from the light, do not die; they continue to live vegetatively and to multiply slowly, deriving energy and food from the soluble organic substances present there. In intermediate light conditions they can live both saprophytically and photosynthetically. In all conditions they probably assimilate nitrate.

The soil fungi are difficult to study and no quantitative methods have yet been devised for estimating the amount of their mycelium in the soil or the numbers of "individuals" present, so that these may be compared with protozoa or bacteria. Mycelium often occurs, particularly in humus soils, in such quantity as to be visible to the naked eye, and obviously to form a significant part of the soil structure. During the last two years Dr. Brierley has worked out quantitative methods which give results capable under proper conditions, of being repeated. The technique was analysed into its constituent factors such as: (1) Sampling; (2) Suspension; (3) Disintegration; (4) Dilution; (5) Plating; (6) Incubation; (7) Counting; and as many as possible of these were standardized. The method finally evolved has been tested by studying the lateral and vertical distribution of fungi in soils of different character. It records only such fungi as can grow under the conditions provided and, in any single experiment, this is only a small proportion of those present. Even so, the numbers obtained are enormous, but, even in soils under such uniform treatment as the Broadbalk plots, their lateral distribution is very unequal, a sample sometimes containing two or three times the number found in another sample taken from a few yards away. Fungi occur in greatest numbers in the top 1—8 inches, they are still plentiful at 12—18 inches, and even in heavy yellow clay have been found at a depth of 6 feet.

Certain soil fungi studied by Dr. Rege rapidly decompose cellulosic materials and, under certain conditions, species of *Coprinus, Aspergillus* and *Acremoniella* decompose straw as rapidly as the whole soil population, and far more rapidly than the soil bacteria alone. Fungi play an important part in soil changes, decomposing plant remains and producing humus, and locking up nitrogen in the form of protein. The exact nature and extent of these changes is still to be explored.

In addition to the above actions, which affect the dead plant-residues in the soil, there are others directly affecting the living plants. Many soil fungi live in active beneficial relation to higher plants, penetrating their tissues and living symbiotically as mycorrhiza. On the other hand the soil is a reservoir of vast numbers of fungi causing disease and death of crop-plants; of these the fungus causing wart disease in potatoes is being studied in detail. Methods to reduce the ill effects produced by these organisms have been devised and are being tested.

Hitherto, investigators in soil microbiology have been greatly handicapped by their inability to sterilise soil without altering it chemically and physically. Dr. McLennan has, however, devised

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a method of drying *in vacuo*, which almost, or completely eliminates living fungi and bacteria, but leaves the soil otherwise unchanged. This is likely to prove of great assistance for future workers.

APPLICATIONS OF SOIL MICROBIOLOGY.

Soil microbiology has already found application in five practical problems :—

1. The inoculation of lucerne and other leguminous crops.
2. The partial sterilisation of glasshouse soils.
3. The fermentation of cellulosic materials with production of a humus manure closely resembling farmyard manure.
4. Overcoming some of the difficulties connected with the preparation of a useful manure from sewage : one of the great unsolved problems of modern civilisation.
5. In the United States the use of sulphur to make a neutral or alkaline soil sufficiently acid to be unsuitable for the development of potato scab (*Actinomyces* scabies), and to render mineral phosphates soluble.

We shall deal with the first four of these in detail.

Inoculation of Lucerne and other Leguminous Crops.

Reference has already been made to the fact that arable husbandry produces the larger output per acre and is therefore the better for the country, while grass husbandry, involving much less expenditure, offers greater possibilities of making some profit and is therefore the safer course for the farmer. The lucerne crop combines the advantages of both systems, giving high output per acre, and at the same time low costs and some hope of profit. It has therefore been the subject of many of our experiments.

Although it was introduced into England nearly 300 years ago, at the same time as the culture of red clover was being advocated, it did not spread beyond a small area in the east; elsewhere it was hardly grown. One important reason for this is that the necessary organism does not occur naturally in our soils while that for red clover does. Mr. Thornton has worked out a method, based on certain continental experiences and some Rothamsted bacteriological investigations, whereby the necessary organisms can be added with the seed; this has been tested during the last two years at about 50 centres in Great Britain, the necessary funds being provided by a grant from the Royal Agricultural Society.

The results fall into two groups : (a) those from the counties where lucerne has been grown so long that the soil has become infected with the proper organism; (b) those from centres where lucerne is rarely grown and the organism is not present in the soil.

In the area where lucerne is an old-established crop, the young plants commonly obtain sufficient nodules for their needs from the "wild" bacteria already present. Inoculation may hasten the appearance of the nodules, because the wild bacteria may be some distance away from the rootlets, but this is of little advantage where there is sufficient nitrogenous plant food in the soil for the young plants. But if the land be weedy or a cover crop be sown, the soil nitrogenous compounds may be used up, causing the lucerne to be dependent on its nodules at an earlier age; inoculation then is beneficial. This is illustrated by the trial at Oaklands, St. Albans, where inoculation produced a slight and temporary benefit with lucerne sown on bare soil, but saved the crop from a serious check where it was sown under a cover crop.

In districts where the bacteria are not naturally present, inoculation is almost always beneficial and often necessary. The effect depends very much on the amount of nitrogen present in the soil; if this is considerable, the plant grows without the organism as fully as other conditions permit, though, of course, it is obtaining its nitrogen from the soil. In this case inoculation may show no effect in the first year till after the first cut has been taken. On the other hand, soils containing but little available nitrogen, show an early response to inoculation. There is always an increase in the quantity of nitrogen contained in the crop per acre; this may be accompanied by a larger weight of crop, or more commonly by an increase both in weight of crop and in percentage of nitrogen. Thus the benefit of inoculation is two-fold, increasing both the yield and the quality of the crop. The advantage cannot always be judged by eye: for the crops may look alike, yet the inoculated one may have the richer feeding value. Some typical results obtained in our trials are shown in the following table :—

Experimenter.	Yield of Lucerne in cwts. per acre.			Percentage of Nitrogen in tops.			Remarks.
	Inoculated.	Untreated.	Difference.	Inoculated.	Untreated.	Difference.	
Lord Clinton, Devon.	53.0	33.0	20.0	3.58	3.35	0.23	Yield increased.
Mr. J. Sheaf, Glos.	21.7	7.8	13.9	3.61	2.62	0.99	Yield and percentage of nitrogen increased.
Col. Meynell, Staffs.	14.5	14.3	0.2	3.09	2.1	1.01	Percentage of nitrogen increased.

Considerable practical difficulty has arisen from the tendency of the lucerne crop to become weedy in its first year, for when young it is more sensitive than most farm crops to competition from other plants. Difficulties have also arisen in connection with varieties: the Provence varieties commonly grown, not being hardy in the north of England. These subjects are being studied; much information has been collected in the publication described on p. 11.

Supply of Cultures.—A demand has already arisen among farmers for cultures for lucerne, and some 900 have been supplied during the past season. This commercial work, however, is not the province of an experimental station, which has neither the staff nor the equipment for the purpose. It is hoped that in the near future arrangements may be completed whereby farmers can obtain guaranteed cultures issued under adequately controlled conditions without diverting the scientific staff from their proper function of carrying out research work.

Partial Sterilisation.

The practice of partially sterilising soil by steam or antiseptics, advocated as a result of investigations at Rothamsted some years ago, is now extensively used in the glasshouse tomato and cucumber growing industry, and has played an important part in raising yields to the levels commonly attained to-day. " Sick " soils, such as those previously dealt with, are now rare : before this stage is reached, the soil is steamed or treated with carbolic acid. They can still be found, however : one studied in 1925 by the Lea Valley Research Station, yielded only 28 tons per acre : a portion that was steamed, yielded 50 tons per acre, while a part treated with carbolic acid yielded 43 tons per acre. The practical problem has now shifted and sterilisation is adopted rather as a preventive than as a cure.

Unfortunately, steaming is costly and the carbolic acid treatment, while cheaper, is rarely as effective. Search has, therefore, been made for more potent chemicals. A heavy oil producd as a by-product from the Mond Gas process was better, giving 6.25 lb. per plant, when applied at only half the usual rate, as against only 5.5 lb. for the full carbolic treatment, and 5.25 on the untreated soil : Steam, however, raised the yield to 7 lb. per plant. This particular oil is not easy to apply, and persists long in the soil. In another nursery it was less effective : the untreated plots yielding 4.8 lb., while the oil gave 5.4 lb., and the carbolic acid 4.3 lb. per plant.

Two organic substances, possible intermediates in the dye industry, have been studied; chlor-di-nitrobenzene and 3.5 dinitro-o-cresol : the former was more effective than carbolic acid even when used in only one-seventh the amount (0.02 per cent. of the weight of the soil instead of 0.15 per cent.), giving an additional 2 tons of tomatoes per acre, as against 1 ton given by carbolic. In these trials the soil was initially good, the yields on the control plots being 44 tons per acre, beyond which it is difficult to go.

In view of the change in the nature of the practical problem, the scientific investigation has been reopened jointly by the Insecticides and Microbiological Departments.

Production of Manure from Waste Cellulose Materials, Straw, Etc.

This process was worked out at Rothamsted by Dr. H. B. Hutchinson and Mr. E. H. Richards in 1920, and has been steadily improved. The exploitation, being unsuitable for an experiment station, is carried out by the non-profit-making syndicate, Adco. The process is now at work in over 30 countries, and thousands of tons of material are treated each year.

The scientific work is being continued in these laboratories. The decomposition proceeds when sufficient moisture and nitrogenous and other nutrients are present, but different waste substances behave very differently under the same conditions. Dr. Rege finds that two factors determine whether a given waste material will decompose quickly to make a good manure: the amount of food or energy material (usually pentosans), this being beneficial, and the amount of lignin, which is detrimental. The relatively high proportion of lignin to pentosan accounts for the unsuitability of certain substances for conversion into manure, but it also suggests that they might become suitable if mixed with other waste material rich in pentosans.

Certain species of thermophilic fungi appear to be the chief agents affecting the decomposition. Dr. Rege has shown that strains of *Coprinus sp.* (*fimetarius?*), *Aspergillus sp.* (*fumigatus?*) and *Acremoniella sp.* (*velutina?*), all common soil forms, can act at temperatures exceeding 50°C, a degree of heat not infrequently attained in manure heaps. Thermophilic bacteria are known, but so far as is ascertained at present, the bacterial decomposition of cellulose does not rest at the humus stage, but runs right down to the final products, carbon dioxide and water.

Microbiology and Treatment of Sewage and other Effluents.

It has long been a reproach to science that, of the 230,000 tons of nitrogen consumed annually by the inhabitants of these islands in their food, only a small part ever returns to the land, the rest being lost or dissipated at great expense. Various sewage sludges have from time to time been tested at Rothamsted, but the only one of promise as a fertiliser (we express no opinion as to any other property), is the Activated Sludge, made by blowing air through the sewage. This contains, when dry, some 6 per cent. of nitrogen in an easily available form, and is worth on the farm up to £4 per ton. Since ordinary sludges contain only 1 or 2 per cent., it was at first thought that the richness of activated sludge was the result of some fixation of gaseous nitrogen, but experiments at Rothamsted (1921-22 Report, p. 50) showed that it came from a better recovery in the sludge of the nitrogen of the sewage, the proportion being 15 per cent. or more (rising in favourable conditions to 27 per cent.), as compared with 10 per cent. by precipitation and 4 per cent. by septic tank methods. Further work has shown that this higher efficiency of recovery is due to a great absorption of ammonia from the sewage.

This absorption is largely due to microorganisms, which assimilate the ammonia and convert it into protein and protoplasm. Bacteria and protozoa both take part, the bacteria assimilating the ammonia and the protozoa assimilating the bacteria; finally, the protozoa are entangled in the sludge and, when dry and dead, contribute largely to its fertilising value. The smooth working of the process depends on maintaining the proper balance between the numbers of protozoa and bacteria. A remarkable instance of failure at one large town studied this year was traced to the introduction of yeast from a brewery into the effluent; this yeast had stimulated the development of the protozoa, which, in turn, had reduced the bacterial population so much that they could not adequately purify the sewage. As soon as the discharge of yeast was stopped, more active purification was resumed.

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An even more efficient absorption of the nitrogen from the sewage can be obtained by allowing the effluent to flow over straw or similar material, which furnishes the bacteria with energy material, causing them to multiply rapidly and assimilate large quantities of nitrogen from the sewage.

These relationships between the nitrogenous and the non-nitrogenous constituents and between the bacteria and the protozoa, furnished the key to some of the difficulties in dealing with sewage and other effluents.

LOSSES OF CROPS BY DISEASES AND PESTS.

The loss caused to fruit growers, farmers and market gardeners, by insect, bacterial and fungus pests, is far greater than is usually realised. No precise estimate is possible, but experts of standing consider that it can hardly be less than 10 per cent. of the crop; in money terms, some £15,000,000 per annum. The trouble is likely to grow worse; improved communications tend to carry plant diseases all over the world, and no method is certain to keep them out from any country.

In order that permanently satisfactory methods of treatment may be devised, it is very desirable to know fully the life history of the fungi and insects concerned and the physiological relationships between the disease-causing organism and the host plant; also to have detailed information about :—

1. The effect of cultivation and manuring on the susceptibility of the crop to disease;
2. The factors determining the rate of increase and of decrease of insect, fungus or bacterial populations;
3. Methods of direct action, such as poisoning, and where practicable, trapping, on the organisms causing disease.

This fundamental information is being obtained, and it is being applied to the control of insect and fungus pests by :—

1. Alterations in time of sowing, methods of cultivation, or manuring;
2. Breaking the life cycle of the organisms in some way (as by the suppression of weeds or other plants that act as hosts), or, in the case of insects, taking advantage of the natural enemies, parasites, etc., that prey upon them;
3. Discovering new insecticides or fungicides that will not injure the crop, but will kill or severely check the pest.

In addition attempts are made to avoid the difficulty altogether by :—

4. Finding some variety of crop plant immune from the disease.

Of these, the first and fourth are the simplest for the farm, though direct action is sometimes possible, as, for example, the use of the fungicide Bordeaux Mixture for potato blight, and various traps for insect pests, like the flea beetle.

Modifications in methods of culture to avoid pests and diseases are already familiar to farmers, e.g., the late sowing of turnips on light land to avoid mildew, though it often causes the crop to suffer from drought by delaying root development. Examples recently tested at Rothamsted include the autumn sowing of beans to avoid black aphis, and the earlier ripening of barley, brought about by earlier sowing and modifications in manuring, to avoid gout fly. This is probably in most seasons the simplest way of dealing with insect and fungus pests on the farm. Dr. Davidson has studied the relationship between the manuring of broad beans and their liability to aphis attack, while in the new glass houses Dr. Brierley will investigate the way in which controlled nutrition of the plant alters its liability to fungus diseases.

No method of dealing with diseases and pests can, however, be entirely satisfactory until more is known of the conditions favouring the growth, dispersion, or migration of insect and fungus populations, and the conditions under which the intrinsic power of the organisms to cause disease becomes increased or decreased. At present great outbreaks can occur of which farmers or fruit growers had no warning, and yet there must have been factors at work causing the excessive multiplication of one out of the many forms of life in the field.

For some years past Dr. Davidson has been studying this problem of multiplication and dispersion, using the Bean Aphis as his material. During the summer period temperature and the physiological condition of the plant profoundly affect the rate of increase of the aphids. At a mean temperature of 70°F. individual aphids took about eight days to reach maturity and start reproducing: at 58°F. (mean) they took about 14 days, and at 55°F. (mean) about 20 days. On beans infected in June, after the setting of the pods, the increase in the number of aphids was 50 per cent. less than on plants six weeks younger, which were more succulent and had not reached the flowering stage. The advantage of autumn sowing is that the plants are well advanced before the winged aphids begin to migrate from the winter host to the beans.

The method of reproduction of the insect is affected by the external conditions. In nature the course of reproduction is for the mothers to hatch out from the eggs in March and give rise to a long succession of parthenogenetic generations. About October sexual forms appear for the first time, eggs are laid and parthenogenetic reproduction ceases. If, however, the temperature be maintained (as under glass house conditions), parthenogenetic viviparous reproduction goes on throughout winter, as well as the development of sexual individuals. At temperatures above about 70°F., the reproduction of the parthenogenetic forms markedly increases, but sexual forms occur more irregularly; the latter are mostly females, though many of their progenitors, the winged forms, die without reproducing. Very few males are produced, so that the normal sexual reproduction by the laying of fertilised eggs does not take place.

The sexual method of reproduction seems also to be associated with the normal winter host, which is a hard, woody plant. Sexual females not only develop much more readily on the spindle tree (the winter host) than on the beans, but in the cages they lay their eggs on the canes supporting the muslin cover rather than on the bean plant.

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Two other aphids have also been studied. The life cycle of the hop damson aphis has been traced from the hatching of the winter eggs in spring on damson trees to the appearance of the sexual forms in autumn. Winged migrants developed on damson and bullace in May. Some were transferred to hops, on which they produced generations of wingless forms until September, and then winged males and remigrants (sexual female producers). Those that had been kept on the damson and bullace reproduced so freely that they killed all the leaves.

Three species of bulb aphids were found on tulip and iris bulbs received from store houses at Covent Garden, in November, 1925. *Anuraphis tulipæ* was the most important. They reproduced rapidly on the dormant bulbs and spread up the flowering spikes of the growing bulbs, destroying them or stunting the flowers. Many winged forms were found but no sexual forms. The fact that winged males but not sexual females occur on tulip bulbs in autumn, indicates that the sexual phase is completed on another plant, used as a winter host.

Considering the multitude of pests with which our crops are beset, it is not easy to understand why any plant should ever survive. There must be natural agents preventing multiplication of insects in this country, and one possibility, which is being studied in the entomological laboratories, is that this natural control is effected by parasites of the insect pests themselves on the ancient principle that : " The little fleas have lesser fleas, and so *ad infinitum.*" There is reason to suppose that, if the parasites could be sufficiently encouraged, they would keep down the insect pests to manageable proportions. The possibilities are attractive, but the difficulties are considerable.

The sugar planters of Hawaii have had the courage to try the method. Dr. Imms visited the islands in 1925 to learn at first hand how it was answering in practice : he was favourably impressed. Authorities in New Zealand are also adopting this method in their efforts to get rid of earwigs, which have become a serious pest. Rothamsted has been asked to find parasites of the earwig and breed quantities for shipment out there. Puparia of the Tachinid parasite, *Digonochæta setipennis,* have accordingly been collected or reared, and sent out; the results will afford valuable experience for other parts of the Empire. Parasites of other pests are also being bred.

The converse problem is also attacked, from an entirely different point of view, also for the New Zealand Government. Gorse has become a serious pest, and all efforts to keep it in check have failed. A weevil, *Apion ulicis,* has been shown by Dr. Imms to destroy some 40 to 80 per cent. of the seeds on gorse shoots selected at random; some 3,000 were collected and shipped to New Zealand, where the feasibility of liberating them on to the gorse-infested regions will be tested. At the request of the entomologist to the Hawaiian Sugar Planters' Association, Dr. Imms has also transmitted a consignment of this same insect to Honolulu, with a view to attempting the control of gorse on the island of Maui. Arrangements have been concluded for collecting, breeding, studying, and shipping to New Zealand quantities of the insect, *Corœbus rubi,* to destroy the brambles which threaten to become so serious a pest there.

Once an insect attack has begun, methods of direct action must be used to cope with it. Two types are in common use, trapping or catching by some mechanical or chemical means, and poisoning by insecticides. Trapping was successfully used against *Bourletiella hortensis,* a species of Collembola, which was found in 1926 to be injuring seedling mangolds on our farm. Laboratory studies by Mr. Davies having shown the dependence of these insects upon humidity, the trapping has to be carried out early in the morning in dry weather, when the leaves are wet with dew. Later in the day the insects leave the plants for the moister soil.

INSECTICIDES.

Two kinds of insecticides are used : stomach and contact. The former are intended to poison the food of the insects and are sprayed on the leaves which they will eat. The latter are brought into contact with their systems in some other way, either as vapours, poisonous spray-fluids, or dusts.

The search for soil insecticides, using the wireworm as the test insect, revealed a number of interesting compounds, among them naphthalene, but was checked by the difficulty that these compounds, though poisonous to the wireworms, serve as food for some of the soil organisms, and are consumed when put into the ground. No way round this difficulty has yet been found.

The work on spray insecticides has been more extensive. There are two kinds :—

1. Those used in winter, which must be strong enough to kill the eggs; fortunately, the trees are dormant, so that fairly potent materials can be used.
2. Those used in summer against the active stages of insects, some of which, such as the aphids, are easily killed. But the trees, being now in leaf, are sensitive to injury, and only those substances are useful which are fatal to the insect and harmless to the tree.

Certain vegetable products completely satisfy this requirement. Nicotine is the best known, but it is expensive. Mr. Tattersfield and Mr. Gimingham have found other vegetable products at least as effective, especially certain tropical leguminous plants, used by the natives as fish poisons. *Derris elliptica,* the Tuba root of Malay, and Haiari, from British Guiana, have yielded a poisonous resin and a colourless, crystalline substance, Tubatoxin, which is excessively poisonous to insects. Other tropical plants, *Tephrosia vogelii, T. toxicaria,* and *T. macropoda,* are also highly toxic to insects, but their poisonous principles have not yet been fully identified.

Many synthetic chemical substances have been investigated, their advantage being that they can be prepared in a pure state under rigidly standardised conditions. They are studied in their proper chemical series, without regard to whether they are yet on the market, the purpose being to draw up a specification showing the types of compound required, to which a technical chemist could work.

The hydrocarbons increase in toxicity with increasing molecular weight up to the point where certain physical properties are so modified that the substance cannot affect the insect. In the aromatic series of hydrocarbons, the maximum toxicity is attained with naphthalene.

Substitution of the hydrogen atoms by various other atoms or groups, increases toxicity up to a certain point, but not beyond. For the hydroxyl group the maximum is at one, for the nitro group at two, and for chlorine at three atoms. These chlor derivatives are anæsthetics, putting the insects into a " moribund " state from which, however, they recover. There is also a position factor, but this varies with the type of compound; ortho-dichlor benzene, is more toxic than para, but paranitrophenol is somewhat more toxic than the corresponding ortho derivative. Dichlornitrobenzene is rather less toxic than chlordinitrobenzene.

The methyl group increases the toxicity when it replaces hydrogen in the ring; xylene is more toxic than toluene and toluene than benzene. But it decreases toxicity when replacing hydrogen in the OH group; the methoxy group is less toxic than the hydroxy group. The toxicity, however, increases with the number of methoxy groups introduced, so that trimethoxy-benzene (1, 2, 3), is more toxic than phenol, and much more so than pyrogallol.

The effect of introducing nitro groups into the hydroxy derivative depends very much on the number added. The first group has little effect; nitrophenol is not much more toxic than phenol. A second group greatly increases this toxicity, 2-4- and 2-6- dinitrophenol and 3-5-dinitro-ortho-cresol are highly toxic both to insects and to eggs; again, however, position comes in; neither 2-5-dinitrophenol, nor 3-5-dinitro-para-cresol being so effective. The maximum is reached with two groups, and the trinitro compounds are less toxic.

The amino group is distinctly toxic, and the imino group even more so; diphenylamine, and dibenzylamine being more toxic than the mono- or tri- derivatives. Nicotine has been closely studied. The units of which it is formed, pyridine and pyrrol, are only feebly toxic; hydrogenation increases toxicity but not to the level of nicotine.

The fatty acids increase in toxicity with increasing molecular weight up to undecylic acid; dodecylic and tri-decylic acids are less toxic; while myristic and higher acids are non-toxic. Some of these acids and their salts are promising as summer washes, and they are being further studied.

Although the work was begun only comparatively recently, it has had important practical results. Derris, Tephrosia, and Haiari, all obtainable from tropical parts of the Empire, are effective as summer washes, while a promising winter wash has been found in 3-5-dinitro-ortho-cresol which, even at the low concentration of 0.15 to 0.25 per cent., and whether free or as sodium salt, completely controlled bad infestations of hop damson aphis on plums and of currant aphis on black currants, while on apples it practically eliminated psylla and aphids, and greatly reduced winter moth; no damage was done to the trees.

The only fungicide studied extensively has been sulphur, for use in the soil. Its action is erratic; it is sometimes effective, but not always; possibly the active agent is not the sulphur itself, but some compound formed in the soil. The subject is being further examined by Mr. Roach.

RESISTANCE AND IMMUNITY OF PLANTS TO FUNGUS DISEASE.

Fungus diseases are being studied by Dr. Brierley and his staff in a somewhat different manner. The easiest way of dealing with them is, where practicable, to avoid their attack by growing immune or resistant varieties. The discovery of potatoes immune to Wart Disease largely solved the practical problem in the great potato growing districts. Much attention has been devoted by Miss Glynne to the study of this immunity. Apparently it does not arise from any power to keep out the fungus, for she has succeeded in inoculating the fungus into shoots of immune tubers, where it continued living to the stage of the summer sporangia, but, up to the present, it has developed no further. Apparently, therefore, the immunity arises from the unsuitability of the tubers for the continued growth and multiplication of the fungus.

Further, the immunity seems to be inherent in the tissue itself; it is not conferred by some chemical agent produced in the leaf and sent down to the tuber. Mr. Roach has grafted immune tops on to some susceptible roots; the new plants grew and developed tubers. Those produced below the graft remained susceptible, while those above the graft were immune, yet both were fed by the same leaves. Conversely, the grafting of susceptible tops on to immune roots gave rise to mixed plants, the tops of which remained susceptible, while the roots remained immune.

Furthermore, many if not most of the common parasitic fungi consist of a greater or lesser number of distinct strains which, although often looking alike, have different powers of causing disease. Each strain has its own geographical or climatic distribution, although these often overlap or coincide, and each strain can cause disease in particular varieties, or ranges of varieties, of host plants. The field problem of disease is, in fact, rapidly being understood as the relation between particular varieties of crop-plant and particular strains of parasitic fungi, and this is throwing much light on the relative immunity of varieties to certain diseases in particular areas and their suceptibility in other areas or under other conditions. This knowledge has already proved of importance in the control of rust diseases of cereal crops.

Dr. Brierley has been studying this problem in the highly variable fungus, *Botrytis cinerea,* which is very destructive on many different kinds of crop and glass-house plants. The apparent variability has been traced to the many constant and closely allied strains of the fungus, very similar morphologically, but differing widely in their physiological properties. There is evidence, which will be tested, that each strain has its particular range of host-plants, on which it can produce disease. One strain suddenly gave rise to colourless, instead of black sclerotia, and this new form remained constant for over 1,000 generations. This type of change is not infrequent in particular strains of many species of fungi, and occurs not only in pigment formation, but in structure, and much more importantly, in physiological and parasitic qualities. There is, thus, always the possibility that a particular strain of fungus may change, and so diminish or extend its power of producing disease in crop-plants.

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As this problem of fungus-strains seems of great importance, much attention has been devoted to it.

Dr. Chodat investigated from this point of view a saprophytic fungus, *Aspergillus ochraceus,* and a tomato parasite, *Phoma alternariacearum,* and observed remarkable genetic changes in pedigree strains. His results are set out on p. 76.

Mr. Dickinson has studied the covered smuts of Oats and Barley, both very destructive fungi. The black bunt or dust of these fungi consists of microscopic spores, about 1/2600 inch diameter, and each of these gives rise to four very much smaller sporidia. By means of his " Isolator," Mr. Dickinson can, with certainty and at will, isolate single sporidia, which are then grown in pure culture, until they form colonies an inch or more in diameter. The sporidia and their subsequent colonies are of one or other of two genders (" sex "), and fusion has been found to occur between them. The microscopic structure and physiology of the pure strains derived from single sporidia of both *Ustilago hordei* and *U. levis,* and of the fusion products when different genders of the one fungus or one gender of one fungus and the other gender of the other fungus combine, have been studied in detail. Neither gender by itself appears to cause disease : only when both genders are present is the plant attacked. The parasitic qualities of these strains will be further investigated and special attention paid to genetic changes.

VIRUS DISEASES OF PLANTS.

Perhaps the most obscure of all plant diseases are those studied by Dr. Henderson Smith, grouped under the name, Virus diseases, including Mosaic, leaf curl, etc. They are spreading, and they cannot as yet be prevented or cured. They are very easily transmitted from one plant to another, not only of the same kind, but, in some instances, of different kinds. They can be transmitted by contact, by insects, and in other simple ways. Their cause is unknown. Many organisms have been isolated from diseased plants, but, so far, none that produces the disease, nor can any casual agent yet be cultivated outside the plant.

There is reason to believe that several distinct types of these diseases, due presumably to different viruses, occur in nature. They may exist singly, or in combination in one plant, either producing symptoms or not; thus potato mosaic and tomato aucuba mosaic both affect tomatoes, giving characteristic symptoms, but the two together produce the harmful stripe disease. Owing to much preliminary work done by Dr. Henderson Smith on these problems, more searching investigation has become possible.

BEE INVESTIGATIONS.

Bees are studied at Rothamsted as honey producers; their diseases are investigated at Aberdeen.

Mr. Morland has been engaged on two problems of importance to beekeepers in this country : the possibility of using metal combs and the best way of arranging the frames in the hives.

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The first of these problems has been solved. Metal combs are unsuited in English conditions for the W. B. C. type of hive* owing to the bees overwintering badly. Their use also necessitated a considerably heavier insulation of the hives than is customary.

The second problem is more difficult and has not yet been solved. The frames may be arranged parallel with the front of the hive, the so-called " warm way," or at right angles to it, the " cold way "; it is not yet decided which is the better.

Mr. Morland visited Eastern Canada and the United States during the months March to June, 1926, in order to study the methods of bee management successfully adopted there; he spent considerable time with the staff of the Bee Culture Laboratory at Washington, D.C., and with Professor Phillips, of Cornell University, to all of whom we owe a debt of gratitude for their courtesy to him.

* The hive designed by Mr. W. Broughton Carr.

METEOROLOGICAL OBSERVATIONS.

Meteorological observations have been systematically made at Rothamsted for many years. The deviation of sunshine, mean air temperature and rainfall from their average monthly values is shown in Figs. I and II for the season 1924-25, and 1925-26 respectively, an excess being recorded above the horizontal line and a deficiency below.

The records now taken at Rothamsted are as follows :—

Continuous self-registering records of :—

Barometric pressure. (Negretti and Zambra barograph.)
Radiation. (Callendar recorder.)
Sunshine. (Campbell Stokes recorder.)
Wind direction and velocity. (Negretti and Zambra anemo-biagraph.)
Rainfall. (Negretti and Zambra hyetograph.)
Drainage through 20 inch, 40 inch and 60 inch gauges. (Negretti and Zambra special design.)
Air temperature. (Negretti and Zambra thermograph.)
Soil temperatures at 4 inch, 8 inch and 12 inch depths, both under grass and in bare soil. (Negretti and Zambra recording thermometers and Cambridge Instrument Company electrical resistance recording thermometers.)

Records taken at stated hours each day.

In addition to the above, the usual barometer, air and soil temperatures and rainfall readings are taken at 9 a.m. ; these are supplemented by further readings at 3 p.m. and 9 p.m. of certain selected factors—wet and dry bulb for relative humidity and dew-point, soil temperature at 4 inch and 8 inch depths. A daily reading is also made of a simple atmometer, to obtain a measure of the amount of evaporation from a wet surface during the preceding 24 hours. Full notes are also made of the general weather conditions.

The detailed information obtained from these records and observations is employed by the Statistical Department in interpreting the crop records, and is also used, together with phenological notes and observations of crop growth, in drawing up the monthly statement for the purpose of the Crop-Weather Report of the Ministry of Agriculture. The continuous self-registering records are used by the Physical Department in their studies of border-line problems between Meteorology and Soil Physics.

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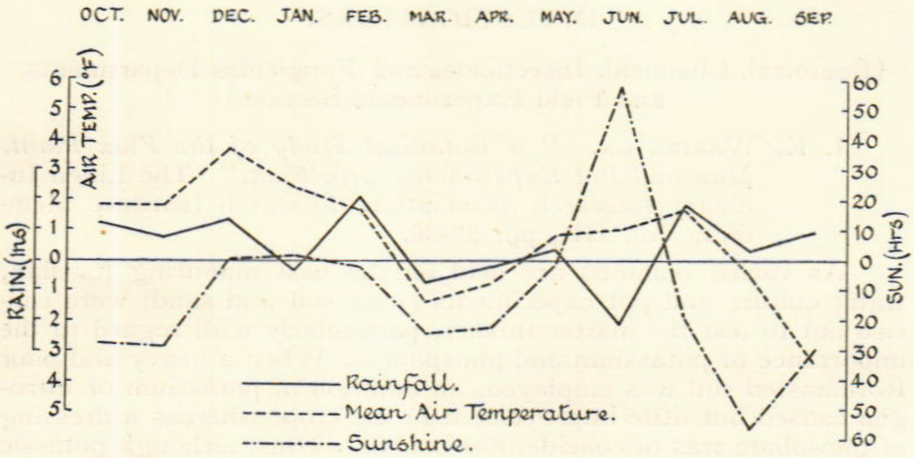

FIG. I.

Deviation from average monthly values of sunshine, mean air temperature, and rainfall. Season 1924-25.

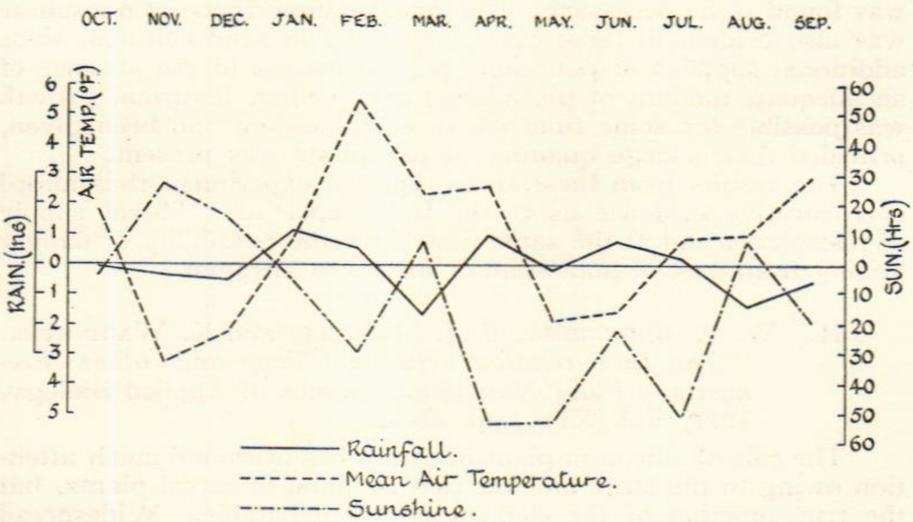

FIG. II.

Deviation from average monthly values of sunshine, mean air temperature, and rainfall. Season 1925-26.