Report for 1933

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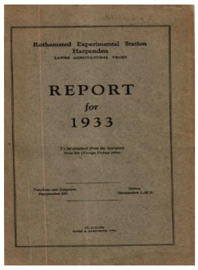
Rothamsted Experimental Station
Harpenden

REPORT
for
1933

Rothamsted Report for 1933

Rothamsted Research

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REPORT FOR 1933

The present-day work at Rothamsted is centred round the production and utilisation of crops : their cultivation, manuring and management, the diseases and the pests that affect them, the influence exerted by soil, season and other factors ; so far as possible quality is studied as well as yield. This latter part of the work is done in association with the expert buyers and users of the crop who, if they cannot always define precisely what they mean by quality, nevertheless recognise it when they see it, so that they can set standards which, if not very definite, are at any rate those that the farmer has at present to accept. Attempts are made in the Chemical Department to express the buyers' and users' requirements in definite chemical terms so that the field experimenter may know exactly what he is expected to produce ; this of course would give him a better chance of success than he has at present.

The Rothamsted work is thus brought into close touch with some of the research schemes set up by various industrial organisations, particularly the Institute of Brewing, the Millers' Research Association, the Sugar Beet Factories, Messrs. Lyons Laboratories, and others. At a certain stage it is generally found more economical to hand certain parts of the work over to the association concerned rather than to keep it at Rothamsted. For the past 12 years investigations into the composition of barley grown under various conditions of soil, season and manuring have been carried out at Rothamsted under the research scheme of the Institute of Brewing. The work has proved exceedingly fruitful and has greatly helped agricultural experts in advising farmers as to the production of malting barley. It was finally so successful that it outgrew the accommodation we could provide and reached the stage where closer contact with the malting and brewing industries was necessary than was possible at Rothamsted. The work was accordingly transferred at the end of March, 1934, to the School of Brewing under Professor Hopkins at the Birmingham University.

This friendly co-operation with the Institute of Brewing has been greatly valued by the Rothamsted Staff, and arrangements have been set up whereby the workers will still remain in touch with each other.

With the discontinuance of the barley work it has been possible to start a fuller study of cellulose formation in plants than has hitherto been possible.

For the purpose of this report the work is divided into field and laboratory investigations ; in practice, however, no sharp line exists between them and all the field work is in close association with the laboratory.

The field work is done at Rothamsted, at Woburn and at a number of outside centres ; the latter involve a large amount of heavy work for which H. V. Garner and E. H. Gregory are responsible. The laboratory work is done chiefly at Rothamsted, but in increasing amount at Woburn also, where the use of electricity

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generously installed at Dr. Mann's expense, has greatly facilitated experimental work. To an increasing extent investigations involving costly and highly specialised apparatus are made not at Rothamsted, but at the Institution best equipped for the purpose, it being found easier and altogether more effective and economical to move the worker or the work than to set up and learn how to use the very costly appliances modern science now demands. Investigations involving X-ray photography are done in association with the Royal Institution and the Textile Physics Department of the Leeds University; vitamin examinations are made at the Sir William Dunn Field Laboratories, Cambridge; dough studies at the Milling Research Institute, St. Albans. One of the staff of the Physics Department is temporarily working at the Johns Hopkins University, Baltimore, using the elaborate high vacuum methods evolved by Professor Patrick. The help afforded by the Directors and Staffs of these various laboratories is exceedingly valuable, ensuring us the maximum of information for the minimum expenditure of time and money.

THE FIELD WORK

As usual during the past few years, the field work has centred round three main problems:

1. The value of organic manures as compared with artificial fertilisers;
2. The effects of artificial fertilisers on the yield and quality of crops; the modifications brought about by soil and seasonal conditions;
3. The processes of soil cultivation.

Organic Manures. So many farmers are now abandoning strict four- or five-course rotations, the feeding of sheep on arable land, and the winter-fattening of cattle in yards, that the supply of organic manure on the farm is much less than it used to be. The purpose of this work is to find out:

1. How the fertility of the soil is likely to be affected in consequence of these changes;
2. Whether the lack of organic manure can be made up in any other way;
3. What value can be put upon farmyard manure as a means of maintaining soil fertility over a long period.

Two rotation experiments have in recent years been started in which organic manure supplied in various ways is compared with artificial manures alone without any organic manure. The treatments include:

1. Straw made into farmyard manure in the old way;
2. Straw ploughed direct into the soil, along with artificial fertilisers;
3. Straw rotted artificially by the "Adco" process;
4. Artificials only, without addition of straw or of any organic matter.

The experiments are intended to run for a number of years, and are designed to bring out both the immediate and the long term effects. The first five-year period is now completed and the results are set out in the Yield Tables, but we prefer to await a longer time before discussing them.

Green manuring receives considerable attention as a practicable method of supplying organic matter to the soil. Our earlier experiments and those at Woburn show that it is very liable to prove ineffective on the light soils that it was especially intended to benefit, and the present experiments are designed to discover the causes of the failure and the best ways of overcoming them. On heavy soils more definite results have been obtained ; mustard ploughed in at Rothamsted has proved an excellent preparation for wheat. But we do not know sufficient about it to be able to advise with certainty.

The ploughing-in of leys affords a simple method of increasing the supply of organic matter in the soil. Its effect is not easily assessed, because the simplest comparison in practice is against a fallow which is itself known to benefit considerably the succeeding crop. In 1933 the yield of wheat following fallow was greater than after any ley, the yield following clover came next, then came the yield following rye grass and clover, while that following rye grass alone was the poorest, being no less than 14 cwt. of grain and 23 cwt. of straw below that following the fallow. The wheat yields after leys cut twice were less than those after leys cut once and then bastard fallowed ; the loss due to the second cutting of the rye grass leys amounted to 2.7 cwt. of grain and 6 cwt. of straw, though on the pure clover ley only the straw suffered, and not the grain, the straw being depressed 3.7 cwt. per acre.

The fallow was so beneficial that dressings of sulphate of ammonia gave no further increase in yield. After the once-cut leys sulphate of ammonia gave a small increase in straw (2 cwt. per acre) but none in grain. After the twice-cut leys sulphate of ammonia added 2.6 cwt. of straw and 0.9 cwt. of grain. Some of the barley in which the leys had been seeded down had received nitrogenous manuring ; this increased the barley and affected the seeds ley, but had no effect on the following wheat.

There was an interesting difference between the effects of the fallow and the clover ley on the wheat crop. Both increased the yield of wheat as compared with rye grass, but in different ways : the fallow by increasing the number of ears per acre, and the clover by increasing the number of grains per ear. This difference may be associated with the time when the nitrogenous nutrients become available ; the fallow acts like an early nitrogenous dressing in promoting tillering ; the clover acts like a nitrogenous dressing that comes too late to increase the number of tillers, but not too late to increase the number of grains per ear.

Poultry Manure. The great increase in the number of poultry has caused a marked increase in the output of poultry manure and has led to many enquiries as to how best it can be used. Under the aegis of the Ministry of Agriculture an investigation into its manurial value has been started ; the field experiments are being made not only at Rothamsted and Woburn, but on various other farms and market gardens. For ordinary agricultural crops it was last year usually inferior to artificials. For the market garden crops, onions and brussels sprouts, it was distinctly superior at some of the centres. More work is needed before any explanation can be given, but the results show that the manuring of market garden crops should not necessarily follow the same lines as that of farm crops.

A proper investigation, planned on modern lines, is clearly needed to find how best to deal with them.

The Effects of Artificial Fertilisers on the Yield and Quality of Crops

The key experiments in this investigation are those on the classical plots at Rothamsted and Woburn and on the six-course rotation more recently established at both centres and intended to run for a long period of years. As, however, the effects of fertilisers are known to be modified by soil and season, numerous experiments are made also on good commercial farms in different parts of the country.

Barley. This work has hitherto been done in association with the Institute of Brewing. The Report of the ten years' experiments has now been published and is obtainable either from Rothamsted or from the Institute.

Sugar Beet. The sugar beet investigations are now made in association with the factory organisation and staffs. Owing to the slender resources hitherto available, the scale of operations has till recently been small. Last year, however, thanks to the co-operation of the factories, a much better scheme was put into operation. The first year's results were discussed at a Conference between the Rothamsted and the factory staffs; as the result a satisfactory experimental programme was drawn up and is now being carried out.

The general purpose is to test the effects of fertilisers at a number of centres, and to make chemical examinations of the soil as described later. Reference to the tables in the full Report shows that the response to fertilisers is less definite than that of potatoes or mangolds, and we do not yet know how to draw up proper recipes for the manuring of sugar beet. The crop, of course, requires manuring, but the ordinary methods seem often to be less effective than for other crops.

Part of the explanation may be in the fact that the sugar beet farms on which the experiments were made were above the average in productiveness. The average of yields on these plots was 11.5 tons per acre, while the average for the country was only 9.0 tons. It is possible that more definite responses would have been obtained on farms below the average in productiveness. This, however, is not the whole explanation.

The experiments at Rothamsted indicate that the subsoil plays an important part in the feeding of the sugar beet. In absence of dung, potassic and phosphatic fertilisers increased the yield of roots and the percentage of sugar, when ploughed in so as to get well down into the soil, to a greater extent than when drilled in the usual way. On the light soil at Woburn the result was reversed. This experiment is being repeated: the yields were too low and the standard errors too high for complete satisfaction.

Sugar beet differs from all other crops in the very high concentration of its root sap, and this cannot fail to modify in some way or other the translocation of sugar from the leaf. A physiological study of the growing crop is needed before the manurial problems can be fully solved.

The spacing of the rows is particularly important. So far as the experiments have gone, the closer the rows the better. At Rothamsted rows 10 inches apart gave 37 per cent. higher yield of roots than rows 20 inches apart; the sugar content was higher and the yield of sugar per acre was raised no less than 41 per cent. The yield of tops was higher also. This increase of sugar content of the root appeared only when the rows were less than 15 inches apart; between the 20-inch and the 15-inch spacing there was no difference.

At Woburn similar results were obtained: rows 10 inches apart gave 21 per cent. higher yield of roots than rows 20 inches apart and 24 per cent. more sugar per acre.

On the other hand, as shown last year, nothing was gained by giving more cultivation than is needed to keep down weeds.

There is clearly a great deal to be learned about the growth of the sugar beet crop. In our experiments the yields have varied from 6 to 16 tons per acre. The average yield over the country is too low to enable the industry to be self-supporting, and it is unreasonable to expect a subsidy to continue unless the fullest efforts are made to raise them.

Potatoes. These experiments, like those on sugar beet, are made not only at Rothamsted and Woburn, but also at a number of farms in various parts of the country. The results since the commencement of the series in 1927 up to and including 1933 were summarised by E. M. Crowther in a conference on Potato Growing at Rothamsted in February, 1934. Many of the experiments were simple 16- or 25-plot schemes, testing different amounts of superphosphate. More complex ones had 36 or 81 plots to test different amounts and combinations of nitrogen and potash, and a few had 27, 36 or even 162 plots to test all three nutrients.

The results are shown in Tables 1 and 2 for the experiments as a whole and also for a special group of highly organic fenland soils. Every experiment undertaken is included; there has been no selection or elimination.

TABLE 1.—Significant responses of potatoes to fertilisers.

Nutrient.	Soil.	Negative.	Insignificant.	Positive.
Nitrogen	Fen	—	2	11
	Others	—	3	16
	Total (32)	—	5	27
Phosphoric Acid ..	Fen	—	—	8
	Others	2	17	13
	Total (40)	2	17	21
Potash	Fen	—	5	9
	Others	—	14	8
	Total (36)	—	19	17
INTERACTIONS:				
N and P_2O_5 ..	.. ..	1	9	6
N and K_2O ..	.. ..	—	19	4
P_2O_5 and K_2O	.. ..	—	16	1

In 90 per cent. or more of the trials there was a definite response to sulphate of ammonia. Fenland soils, which are rich both in total and in available nitrogen, responded to sulphate of ammonia just as frequently as the mineral soils.

Each of 8 fenland soils responded to superphosphate, but only in 13 out of 32 trials did the mineral soils give significant responses to superphosphate. In two experiments superphosphate definitely reduced the yield. In three experiments on acid peat—" moss " soils in Lancashire—there was no phosphate response. It is clear, then, that fenland soils stand out quite distinctly from other soils in their need for phosphate, as is, of course, well recognised in practice.

In 36 potash trials one half gave definite responses, with some indication that fenland soils were more responsive to potash than mineral soils. In so far as the soils tested in these experiments were typical, they show that sulphate of ammonia is almost always effective and that superphosphate is effective on fenland soils. Superphosphate on mineral soils and potash on all soils are much less consistently successful in increasing yield. The experiments show that sulphate of ammonia and superphosphate quite often " interact positively," i.e. they frequently reinforce each other's effect. Thus in 6 out of 16 trials the response to either sulphate of ammonia or superphosphate in the presence of the other manure was significantly greater than in its absence. This harmonises with the striking effects of superphosphate on fenland soils, for these are known to be rich in available nitrogen. The " interactions," or reinforcements of effects of nitrogen and potash and of potash and phosphate were much less frequent. Positive significant effects were obtained 4 times out of 23 for nitrogen and potash, and only once in 17 trials for potash and phosphate.

The size of the response is shown in Table 2. In most of these experiments the standard error per plot was about 15 cwt. per acre, and a response of 1 ton per acre would be detected as significant in an experiment with 16 or 25 plots. The results are set out by showing the number of experiments in which the response in cwts. of potatoes per acre was from 0 to 10, 10 to 20, and so on.

TABLE 2.—Response of potatoes to fertilisers.

		Decrease		Increase.						
Response in cwt. per acre		20–10	10–0	0–10	10–20	20–30	30–40	40–50	50–60	Over 60
Nitrogen (0.4 cwt. Nitrogen per acre = 2cwt. sulphate of ammonia)	Fen Soils	—	1	1	1	1	6	2	—	1
	All Soils	—	3	3	5	7	9	3	1	1
Phosphoric Acid (0.6 cwt. P_2O_5 per acre = 4·5 cwt. super)	Fen Soils	—	—	—	1	2	2	1	2	—
	All Soils	3	9	8	7	4	5	2	2	—
Potash (1.0 cwt. K_2O per acre = 2 cwt. sulphate of potash)	Fen Soils	1	3	1	3	2	—	—	2	2
	All Soils	1	7	11	7	4	—	—	3	3

TABLE 4.—Marks for Quality of Steamed Potatoes (1929).

Cwts. K_2O per acre.	Woburn.	Rothamsted.	Cwts. N per acre.	Woburn.	Rothamsted.
0	32.6	28.5	0	34.4	29.2
0.5	33.6	29.5	0.3	33.3	29.3
1.0	34.5	29.6	0.6	32.9	29.1

The practical conclusion is that the quality is determined by soil and season, and yield by the fertiliser dressing. Quality is not likely to be affected one way or the other by a good scheme of complete manuring, and so the grower can aim at producing heavy crops without fear that the quality will suffer. This same result was obtained for barley.

Chemical analysis shows consistent changes in composition produced by fertilisers which, however, are small and nothing like so marked as those obtained on the same soil in different seasons. The amount of dry matter in the fresh tubers was but slightly affected by sulphate of potash but somewhat reduced by potassic fertilisers containing chlorine, *e.g.* muriate of potash and still more by 30 per cent. potash salts. (Table 5.)

Sulphate of ammonia consistently increased the nitrogen content of the dry tuber. Superphosphate reduced the nitrogen content of the dry tuber in those years in which it greatly increased the yield. Potash had no effect on the nitrogen content of the dry tuber.

Although the potato is essentially a carbohydrate food, it is an efficient crop for converting inorganic nitrogen—sulphate of ammonia—into vegetable protein. The recoveries in the potato tuber of the nitrogen added as sulphate of ammonia in the Rothamsted experiments of 1929 to 1932 were 21, 43, 29 and 36 per cent., respectively; in addition, 20 per cent. may be recovered in the haulm.

TABLE 5.—Effect of fertilisers on the quality and composition of Potatoes.
Dry matter per cent.

	No Potash.	Sulphate of Potash.	Muriate of Potash.	30 p.c. Potash Salt.	Rate of Dressing cwt. K_2O per acre.
Woburn, 1929 ..	27.5	26.7	26.2	24.8	1.0
Rothamsted, 1929	26.1	25.9	24.9	24.2	1.0
,, 1930	23.1	23.3	22.7	22.1	0.8
,, 1931	20.9	20.5	20.2	20.2	0.8
,, 1932	22.6	22.1	—	—	0.8

Effect of Sulphate of Ammonia on Nitrogen Content of Dry Matter of Tubers

Rate of application, cwt. per acre.	0	1	1.5	2	3	4
Woburn, 1929	1.44	—	1.49	—	1.54	—
Rothamsted, 1929	1.52	—	1.58	—	1.65	—
,, 1930	1.34	1.40	—	1.47	—	—
,, 1931	1.40	1.41	—	1.46	—	—
,, 1932	1.28	—	—	1.35	—	1.43

The responses to nitrogen were as a rule much the same whether the yields were high or low. Two cwt. of sulphate of ammonia per acre added between 1 and 2 tons of potatoes to the yield in just one half of the experiments, and the other results are grouped round these values, some above and some below, in such a way as to make it possible to speak of a general nitrogen response at the rate of about 15 cwt. of potatoes per cwt. of sulphate of ammonia.

The responses to superphosphate were very variable. In over one-quarter of the trials the superphosphate plots yielded less than those without superphosphate. In one-third of the trials the response exceeded 1 ton per acre; these more responsive centres included 7 of the 8 fenland trials and 6 of the 32 trials on other soils. The responses to superphosphate had no obvious connection with the productiveness of the soil. The yields in the various experiments ranged from 3 to 17 tons per acre, yet some of the most productive soils responded while some of the low yielding soils did not. We still have a good deal to learn about the factors determining response to phosphate.

The responses to potash, on the other hand, showed some connection, though not a close one, with yield. At most of the centres where the responses had been small the yields were over 10 tons per acre, which is well above the average for the country. At half of the centres the responses were less than 10 cwt. of potatoes per acre. Thirty of the 36 trials fall into a consistent group with small responses, but the other six centres (4 on light fenland soils and 2 on light sands) show very large responses of about 3 tons per acre. In isolated soils potash fertiliser doubled the crop. Some soils have an acute potash shortage, but the majority of potato soils show only slight effects on yield.

The reinforcement of effect when superphosphate supplements sulphate of ammonia or when sulphate of potash is added—the "interaction" mentioned above—is well shown on the fen soils. The results are given in Table 3.

TABLE 3.—Yields of potatoes, tons per acre. Fen soils.

	Used alone.	Used with Sulphate of Ammonia.	Difference (interaction).
Increase due to Superphosphate—			
Little Downham, 1932 ..	2.96	4.40	1.44 ± 0.71
March, 1932	1.03	1.92	0.89 ± 0.24
Increase due to Sulphate of Potash			
Thorney, 1933 (no dung)	3.49	4.78	1.29 ± 0.52
Thorney, 1933 (dung) ..	0.74	2.19	1.45 ± 0.52

The chemical work on the composition of potatoes has continued on the lines of the quality investigations made in conjunction with Messrs. Lyons laboratories in 1929. Fertilisers had but little effect on the cooking quality of the potatoes: sulphate of ammonia slightly decreased and potassic fertilisers slightly increased the quality for steaming, but neither affected the quality for frying. The effects, however, were small and nothing like as marked as the effect of soils. By no fertiliser treatment was it possible to raise the quality of the Rothamsted potatoes to the level of those grown at Woburn. (Table 4).

The Rothamsted potato experiments of 1927 to 1932 (recorded in the Reports for those years) gave smaller responses to potash fertilisers than had been obtained on the same fields from 1921 to 1926. The explanation may be that in the earlier years little stock was kept and little dung was used on the farm. Further, in several years of the earlier period the potatoes received no dung but large dressings of fertilisers. In the later years the potatoes always had a basal dressing of dung and the dressings of fertiliser were smaller.

TABLE 6.—Yield of Potatoes, Tons per acre, Outside Centres.

Centre.	Soil.	Dung.	*Sulphate of Ammonia.* None.	*Sulphate of Ammonia.* Increased yield.	*Sulphate of Ammonia.* Quantity used, cwt per acre.	*Sulphate of Potash.* None.	*Sulphate of Potash.* Increased yield.	*Sulphate of Potash.* Quantity used, cwt per acre.	*Superphosphate.* None.	*Superphosphate.* Increased yield.	*Superphosphate.* Quantity used, cwt per acre.
Potton* (Earlies)	Sand	Added	3.16	0.05	1½	2.74	**0.88**	2	3.09	0.19	3
Mineral Soils.											
Wisbech ..	Silt	None	12.25	**1.91**	4	12.87	**0.86**	4	12.42	**1.63**	9
Sutton Bonington (Midland Coll.) ..	Light loam	Added	9.94	0.36	3	9.92	0.12	3	—	—	—
Owmby Cliff, Lincs. ..	Limestone	None	9.5	**0.42**	1	—	—	—	—	—	—
Swanley (Hort. Coll.) ..	Gravel loam on chalk	Added	8.41	0.16	3	—	—	—	—	—	—
Fenland Centres.											
March† ..	Heavy fen	None	10.58	**1.63**	2	11.46	−0.12	1.5	—	—	—
,, ..	Siltyfen	Added	10.33	**2.37**	2	11.22	**0.58**	1.5	—	—	—
,, ..	Light fen	Added	12.38	**0.65**	2	12.18	**1.05**	1.5	—	—	—
,, ..	Light peaty fen	None	9.16	−0.17	2	7.56	**3.02**	1.5	—	—	—
Thorney† ..	Light fen	None	8.46	**1.08**	2	6.93	**4.14**	1.5	—	—	—
,, ..	Light fen	Added	9.60	**1.14**	2	9.43	**1.46**	1.5	—	—	—
Wimblington	Light fen	None	7.49	**1.98**	3	7.02	**2.16**	1.5	—	—	—
Little Downham	Heavy fen	None	11.42	**3.76**	2	—	—	—	11.86	**3.61**	6
March	Peaty fen on clay	None	12.24	0.24	2	12.30	0.12	2	11.75	**1.21**	7
Microplots.											
Welshpool ..	Medium loam	None	7.63	**1.32**	3	—	—	—	—	—	—
Bakewell ..	Limestone	None	6.65	**1.64**	3	—	—	—	—	—	—
Burford ..	Brashy loam	None	6.81	0.44	3	—	—	—	—	—	—
Staindrop ..	Garden	None	10.62	1.28	3	—	—	—	—	—	—
Godalming ..	Sandy	None	7.83	**2.32**	3	—	—	—	—	—	—
Hull	Clay	None	11.57	0.52	3	—	—	—	—	—	—
Fakenham ..	Sandy loam	None	8.61	0.66	3	—	—	—	—	—	—
Newcastle, Staffs ..	Heavy	None	12.15	0.21	3	—	—	—	—	—	—
Kimmel ..	Light loam	None	5.21	0.17	3	4.98	0.63	3	4.79	**1.01**	4
Doncaster ..	Medium loam	None	—	—	—	3.58	**7.60**	3	—	—	—

* Nitrate of Soda given. † Muriate of Potash given. (The figures in heavy type are significant.)

In the 1933 experiments when the summer was unusually dry, nitrogen had somewhat less than its usual effect though the increases were very profitable. Potash acted well at practically all the centres, especially on the light peaty fens, but most of all on the medium loam at Doncaster. It was the only fertiliser effective for the early potatoes. Superphosphate acted unusually well, giving four successful responses in five trials and showing up particularly well on the heavy soil at Rothamsted. (The results are given in Table 6.)

Alongside of the field work on the potatoes physiological studies of the growing plant are made by D. J. Watson to find out what the fertilisers do in the plant. Potassic fertilisers decreased the concentration of sucrose in the leaf during the hours of daylight but not during the darkness. They had no recognisable effect on the reducing sugars, however.

Grassland

The manuring of grassland alters not only the yield and composition of each of the individual species of plants but also the balance of competition between one plant and another and therefore changes the entire flora. Two groups of investigations have been made : with phosphatic fertilisers, which broadly speaking tend to give a more pronounced leguminous herbage ; and with nitrogenous fertilisers, which tend to make the grasses dominant.

The work on phosphatic fertilisers has been done under the aegis of the Basic Slag Committee of the Ministry of Agriculture ; it involves a large amount of analytical work for which R. G. Warren is responsible. The key experiments are made at Rothamsted, and numerous experiments are made at various centres in the country. The outstanding result is the general superiority of superphosphate and of high soluble slag over the low soluble slag and, on non-acid soils, over ground mineral phosphate. On an average the high soluble slag has been about three times as effective in supplying phosphate to the plant as the low soluble slag containing equal amounts of phosphate, while the mineral phosphate has been on certain acid soils about as good as the high soluble slag and on non-acid soils about as poor as low soluble slag. The percentage recovery of phosphoric acid over the three or four years is given in Table 7.

TABLE 7.—Percentage Recovery of Phosphoric Acid in 3 or 4 Years in Grassland Experiments.

Season.	Treatment of grass.	Centre.	Geological origin of soil.	Soil pH reaction.	Low-soluble slag.	Gafsa mineral phosphate.	High-soluble slag.	Superphosphate.
Neutral or calcareous soils—								
1930-33	Hay	Braintree, Essex ..	Calcareous boulder clay	7.8, alkaline	3	3	17	17
1930-33	Hay	Badminton, Glouc.	Oolite	7.2, neutral	2	4	13	16
1931-33	Repeatedly mown, ungrazed ..	Much Hadham, Herts	Calcareous boulder clay	7.1, neutral	8	8	34	30
1931-33	Grazed, mown once annually ..	Much Hadham, Herts	Calcareous boulder clay	7.1, neutral	6	8	26	30
				Mean	5	6	22	23
Acid soils—								
1930-33	Hay	Chesterfield, Derby	Lower coal measures shales ..	5.1, very acid	6	13	13	15
1930-33	Hay	Lydbury, Salop	Wenlock shales ..	5.2, very acid	10	19	14	18
1930-33	Hay	Cockle Park, North	Boulder clay ..	4.9, very acid	3	10	7	8
1930-33	Hay	Northallerton, Yorks ..	Boulder clay on keuper marl ..	5.2, very acid	5	16	18	21
1930-33	Repeatedly mown, ungrazed ..	Dartington Hall, Devon ..	Devonian shales	5.2, very acid	6	29	31	32
				Mean	6	17	17	19

This superiority of the soluble phosphates shows itself not only in increased yield and larger proportion of good fodder plants, but also in the higher content of phosphorus in the herbage, whereby its feeding value per ton is almost certainly enhanced. A special feature of the work has been the chemical control of the phosphorus uptake by the crop, and this has proved of great help in showing the relative values of the different fertilisers.

So far the experiments have not shown where the line is to be drawn between the high soluble and the low soluble slags. Hitherto this problem has been unimportant, because most samples on the market were either above 75 per cent. or below 30 per cent. solubility. Now, however, there seems the probability that slags of intermediate solubility will be offered for sale and the work is being extended to cover these.

Fodder Mixtures. Further studies were made of the yield and composition of fodder mixtures containing different proportions of oats and vetches, grown with and without nitrogenous manure. The yields of dry matter per acre were highest when the seed mixture contained 3 bushels of oats to 1 bushel of vetches. Nitrogenous manure increased the yield, but not significantly more for one mixture than for another; previous work has shown that the increase is in the starch equivalent per acre and not in the quantity of protein.

Lucerne. The inoculation experiments are described later. (p. 36)

For some time past Professor W. Southworth, who is working at Rothamsted after his retirement from Canada, has been experimenting with hybrids of lucerne and black medick, and has obtained at least one promising sort considerably more vigorous in early life than the ordinary Provence variety. The percentage of plants that died during the first year were :

	The new sort.	Provence.
Rothamsted ..	1.7	23.4
Woburn	0	15

The new sort is at least as productive as the Provence, both of fodder per acre and of seed, and further experiments are being made.

Clover. Cultures of the nodule organism have been prepared which in preliminary experiments made in association with Professor Stapledon greatly improved the "take" of clover on newly sown upland grassland. Should any extensive resowing seem likely to occur, this work ought certainly to be expedited so as to ensure supplies of the cultures in time to meet the farmers' needs.

Marrow stem Kale. This is proving one of the most valuable fodder crops on the farm. In our numerous experiments yields of 25 or more tons per acre are frequently obtained on our poor heavy land. It responds remarkably well to nitrogenous manuring, and is one of the best crops for converting fertiliser nitrogen into valuable animal food.

The residual effect of the farmyard manure applied to the 1932 kale crop at Woburn was studied by following it with barley in 1933, and comparing the yield with that given by sulphate of ammonia. On plots that had dung in 1932 there was an increase of 12.2 cwt. of green matter over the plots receiving no dung; while 0.2 cwt. of nitrogen applied as sulphate of ammonia in 1933 gave an increase of 20.7 cwt. per acre. The residual effect of the dung was therefore

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approximately that of 0.118 cwt. nitrogen per acre, or 0.6 cwt. sulphate of ammonia. No residual effect of sulphate of ammonia applied in 1932 could be detected.

Mangolds. In the Statistical Department an examination of the yields of mangolds on Barnfield for the years 1876 to 1930 has been completed by R. J. Kalamkar. The new facts brought out are that the deterioration of yield usually observed where one crop is grown continuously has not been pronounced on the plots receiving farm-yard manure or complete artificials including nitrate of soda, but it becomes more marked when either nitrogen or potash and phosphate are omitted. Slow changes in yield other than deterioration are unimportant except on the dunged plots. The annual variance is increased by nitrogenous manuring but decreased by potassic fertiliser and also by rape cake or dung. Variations in rainfall do not account for the variations in yield due to annual causes though rainfall in excess of the average appears to be somewhat harmful when it comes in Spring (mid-March to end of May) and beneficial when it comes in June and July.

The value of fodder crops. Chemistry is not yet sufficiently advanced to give a complete statement of the feeding value of these fodder crops, and it is still necessary to use the animal as the means of testing. It is proposed to use sheep and pigs, and feeding experiments of a new type have been designed to eliminate the effect of variations in location of the stalls and to reduce the effect of individuality of the animal.

THE SOIL CULTIVATION EXPERIMENTS

In view of the changes brought about by mechanisation in the cultivation of wheat and other cereals, a number of experiments have been made on different methods of seed-bed preparation, including shallow and deep ploughing and rotary cultivation, each in conjunction with spring harrowing, rolling and top dressing with sulphate of ammonia. No significant differences in yield of grain were observed between any of the treatments, and the choice of the different methods would apparently be dictated by their relative cost and convenience. Neither rolling nor harrowing increased the yield.

The conditions were, however, unusual in that sulphate of ammonia had no effect on the yield of grain. On the other hand the yield of straw was increased by the addition of nitrogen. The response to nitrogen varied according to the cultivation. Rolling increased it.

It would be interesting to know whether the grain would show similar responses to cultivation on land where sulphate of ammonia increased its yield.

THE IMPROVEMENT OF FIELD PLOT TECHNIQUE

Some interesting advances have been made during the year in the theory of field plot design, particularly in the methods available for combining several different problems into one experiment. Here the method of "partial confounding" has been developed; this considerably increases the utility of "confounding" for combining different problems into one experiment, since it serves to provide more flexible arrangements. The methods of analysis when the data are incomplete have been extended to cases where several plots are missing, and their validity established. Convenient methods of forming Latin squares for field experiments have been placed on record.

The working out of the experimental data has now become a formidable task, as shown by the following numbers of plot yields analysed :

Year.	Number of Experiments.			Plot Yields Analysed.		
	Rothamsted and Woburn.	Outside Centres.	Total.	Rothamsted and Woburn.	Outside Centres.	Total.
1925	8	—	8	328	—	328
1926	13	4	17	740	73	813
1927	12	5	17	802	150	952
1928	11	12	23	1267	392	1659
1929	12	12	24	1565	352	1917
1930	14	24	36	1341	918	2259
1931	13	41	52	2044	1968	4012
1932	17	49	64	2153	3792	5945
1933	15	78	93	2085	4443	6528

FARM HUSBANDRY PROBLEMS

With the completion of the farm equipment it has now become possible for the farm staff to take up a number of farm husbandry problems which previously had to be neglected. Three have already been started, and it is hoped to take up others as opportunity arises.

Sources of power about the farm buildings. With the setting up of the grid system, many farmers are now in a position to obtain electric current as a source of power, and naturally they wish to know how its cost compares with that of the internal combustion engine. A programme of investigation was drawn up early in 1931, when Mr. Borlase Matthews generously gave his services in working out plans for a complete installation. It was not, however, possible to obtain the necessary capital, and the work could not be put in hand. In 1932, however, Sir Hugo Hirst gave a munificent donation that assured adequate equipment, and the North Metropolitan Electric Supply Company agreed to connect up the farm, and supply current at a special rate so that the investigation could be begun in real earnest ; Mr. Rowland and other officers of the General Electric Company thereupon designed the installation and selected the equipment : The purpose of the work is to see what electricity can usefully do about the buildings under the conditions of a good commercial farm, and how the costs compare with those of the older methods. The Royal Agricultural Society made a grant out of its Research Fund to allow of the appointment of a Recorder, and a scheme of measurements was drawn up after discussion with the Oxford Institutes of Agricultural Engineering and of Agricultural Economics. The various operations, threshing, grinding, etc., are done alternately by an electric motor and by an engine (usually a tractor) and the work done, the time required, the units of electricity or gallons of fuel consumed, are all recorded, along with such other measurements as give further necessary information about the produce. We shall thus be able to find how many units of electricity are equivalent to 1 gallon of fuel for work about the buildings.

Under ordinary commercial conditions of working the power required to do a particular piece of work varies widely according to the setting of the machine and the condition of the produce it deals with, but these variations are reduced to a minimum in successive tests. A further result of this investigation will be to furnish agricultural engineers with information about the wastage of power that so often occurs on farms.

For purposes of these investigations the International Harvester Company kindly placed a new tractor at our disposal in order that we might include it in the tests in comparison with one that has done five years' good work on the farm.

Sheep husbandry investigations. These investigations were begun by the late H. G. Miller, and their general trend was foreshadowed in two papers, one read before the Rothamsted Conference on Sheep Husbandry *, and the other read before the Farmers' Club in 1931†. The experiments include some on the flushing of ewes and the treatment of the breeding flock. A flock of four nippled ewes is being built up to see if they are better mothers than the usual animals with two nipples only.

Bacon-pig investigations. The herd consists of Wessex Saddleback and cross-bred sows crossed with a Large White boar.

The experimental work on pigs was extended during the year by the introduction of a complex experiment, designed to test the possibility of applying to animal husbandry problems the methods which have been so successful in increasing the efficiency and validity of field plot experiments.

Individual feeding was resorted to, and three blocks, each of 24 pigs, were formed, to test the effect of green food, of dry feeding *versus* wet feeding, and of variation in the numbers of pigs per pen (equal floor space being assigned to each pig). The experiment was very successful. The results afford a striking demonstration of the importance of green food in the dietary of the growing pig. They also show the advantage of wet over dry feeding, this being attributable to the greater food consumption of the pigs on wet food. There appeared to be no differences due to variation of numbers in a pen. The standard errors per pig were satisfactorily low. The details of design and numerical data are given in the Yield Tables at the end of the Report.

The experimental design adopted embodies several novel and interesting features, and the methods employed should prove of great value to those who have to undertake this type of investigation. The work is being continued this year.

These various experiments are being continued under J. R. Moffatt ; their results are not yet sufficiently advanced for publication. The efficiency of the management is attested by the circumstance that the lamb carcase sent to Smithfield was awarded a First Prize, the pig carcase a Highly Commended, while the bacon factory place a large proportion of our animals in the A class.

PLANT BIOCHEMISTRY

The work on fertilisers and crops has expanded so much that it has been necessary to make further provision for chemical examination of the growing crop, and A. G. Norman has therefore been put in charge of this work. In conjunction with Mrs. Norman, he is studying

* Rothamsted Conference Reports, No. 12, obtainable at the Station.
† Jl. Farmers' Club, 1931, pp. 106-117, obtainable from the Sec. Farmers' Club, 2 Whitehall Gardens London.

especially the transition from the early stage in the life of grass and cereals when the plant is rich in protein and in minerals, to the later stage when it contains much cellulose. This completely alters its feeding value and much affects the return a farmer obtains from his fertilisers.

These studies of cellulose will be greatly facilitated by the collaboration of the Textile Physics Department of the Leeds University, Mr. Astbury having kindly undertaken the X-ray photography of the various samples whereby their intimate structure is revealed.

THE NATURE OF THE SOIL

Field experiments necessarily remain purely empirical and limited in value until sufficient is known about the soil to show how far the results obtained on one field are likely to be obtained on another. Laboratory investigations of the soil are therefore made on the physical, chemical and microbiological sides.

PHYSICAL PROPERTIES OF THE SOIL

These are studied in the Physics Department. B. A. Keen's well-known investigations of the soil moisture relationships have formed the basis of much subsequent work, including that of W. B. Haines, which showed that the old " equilibrium values " of soil moisture content had no actual existence although certain characteristic moisture contents could be recognised. Some of these are now being studied by G. H. Cashen using sensitive electrical methods; they correspond to some kind of combination with successive but uniform increments of moisture. The well-known " sticky point " appears to be the seventh of these stages.

Kaolin appears to behave like clay, and as its chemical and physical composition are better known than those of clay, it has proved useful in the interpretation of the clay phenomena.

Water, however, is not the only liquid with which the clay enters into some sort of combination. E. W. Russell has studied the behaviour of clay and various organic liquids, using the change in specific volume of the clay when immersed in them as a measure of the degree of the combination taking place. So far as can be ascertained, only polar liquids interact with clay, and the extent of the interaction (i.e. the reduction in specific volume) is approximately proportional to :

(1) The number of exchangeable ions the clay can hold in equilibrium with a buffer of pH7 ;

(2) The mean charge density on the surface of the ions ;

(3) Some property of the clay expressed by the shape of the clay titration curve.

When the liquids evaporate from the wet paste the clay particles tend to cohere, forming aggregates or crumbs. This occurs, however, only in polar liquids, and it is marked only when the clay has an appreciable base exchange capacity, when its particles are small, and the exchangeable cations and polar groups of the liquids are also small.

All these phenomena can be explained on the hypothesis that the exchangeable ions of the clay particles interact with the molecules

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of the liquid if these are polar, the interaction being the simple orientation of the dipoles by the electric charges on the ions and the clay. This hypothesis promises to be useful in furthering our knowledge of clay and of crumb formation in soil. E. W. Russell having been awarded a Rockefeller Fellowship, has proceeded to Professor Patrick's laboratory at the Johns Hopkins University, Baltimore, to continue the investigation, using the special high vacuum technique which has been developed there.

A new line of investigation, the interpretation of which is not yet in sight, has been opened up by R. K. Schofield. The curves expressing the relation between calcium uptake by different clays from calcium salt solutions of different pH values vary according to the clay, but the variation occurs only at pH values below about 9.8 ; above this the curves are all similar. Whether this is a specific property of the calcium ion, or whether other ions behave similarly, is not yet known. The results are, however, curious and almost certainly conceal some property of considerable importance.

The clay investigations are already throwing light on other problems besides those relating to the soil. G. W. Scott Blair is making with dough a series of experiments parallel to those already made with clay, dealing especially with viscosity. He and R. K. Schofield first cleared up a difficulty on the theoretical side by showing how to modify the ordinary Maxwell equation expressing the relation between rate of change of strain to rate of change of stress so as to make it fit the facts in regard to clay and similar substances. The new results are now being used to study the stickiness of dough in association with the Research Institute of the Flour Millers' Association. This particular property is much used by the baker in assessing the value of the dough ; it is being estimated by means of a Kachinsky balance. The rheogram measurements already described have been extended and for the first time the important elastic and plastic properties of dough have been expressed in absolute (c.g.s.) units, while standardised methods have been set up for preparing reproducible doughs from flour samples.

The effect of yeast on these various properties has been studied in conjunction with L. W. Samuel.

The important technical applications of these various results are worked out at the Flour Millers' Association Laboratory. The work affords an excellent example of the way in which a scientific investigation *properly done* may widen out wholly unexpectedly and throw light on problems far removed from those originally in mind.

CHEMICAL PROPERTIES OF THE SOIL

The work during the past year has been concerned chiefly with the plant nutrients in the soil. The fertiliser experiments at Rothamsted, Woburn and the outside centres are all organised from the Chemical Department, and a considerable part of the time of the staff is taken up with the chemical work associated therewith.

Side by side with the field experiments on organic manures, E. M. Crowther and his staff have since 1927 been studying their decomposition and that of crop residues in the soil, to find the relation between the production of "available nitrogen" and the nature of the organic material and the general soil conditions, including the time interval between addition of the material to the soil and utilisation of the nitrogen compound by the plant. The starting point was the remarkable fact that green manures, especially tares, do not keep up the productiveness of the light soil at Woburn for wheat. The conditions in the field favour rapid decomposition of the crop residues and loss of nitrate by leaching, but this is not the whole explanation. E. M. Crowther and H. H. Mann show that in pot experiments barley benefits from the nitrogen of the tares so long as it is sown immediately after the burying of the green crop, but it does not benefit from the nitrogen contained in the mustard. The effectiveness of the nitrogen speedily decays, however, and if the sowing is too long delayed, the cereal gains but little from the tares. This is not entirely a drainage effect, for it happens whether the soils have been leached or not. At Rothamsted the nitrate stored up during a summer or autumn fallow suffered a similar " decay " : it fell to a low level during winter. Yet the wheat crops that followed did not suffer in the same way : the yields corresponded more closely with the levels of nitrate present in autumn, and varying with the treatment, than to the uniformly low levels of the early spring. E. M. Crowther suggests two possibilities, both of which are being further studied : the nitrate may be converted by micro-organisms into an insoluble form which is later broken down and becomes available to the crop ; or it may be washed into the subsoil and held there till it is taken up by the crop. Usually the plant nutrients are supposed to be specially associated with the surface soil, and the subsoil is often neglected by chemists. The above results suggest that the production and utilisation of plant nutrients is related to the structural and textural characters of the whole of the soil profile.

In acid soils and on grass land, nitrate formation does not proceed far, and considerably more ammonia accumulates. Evidence is adduced that grass frequently or even normally obtains its nitrogen not from nitrate, but from ammonia.

Soil analysis. Now that so many field experiments are being made at outside centres by the Rothamsted staff or in association with them, it has become possible to take up once more the important question of soil analysis. Nothing in agricultural science has had a more chequered career. Hailed at the outset as a great scientific triumph, it had to be abandoned because its results were so often useless to the farmer. It is now recognised that two distinct problems are involved : soil analysis for advice in regard to manuring, and soil analysis for the characterisation of soils for purposes of soil surveys. Two groups of methods are therefore needed, and these are being worked out in the Chemical and Physical Departments.

For purposes of advice on manuring it is usual to adopt some " availability " method. A number of these have been devised and some are fairly well received on the Continent. They and others are being tested in the Chemical Department on the wide range of soils obtained from the replicated plots at our outside centres where, therefore, the actual manurial response is known.

For soil survey purposes, new methods of characterising soils are being studied both in the Chemical and Physical Departments, and then tested on groups of soils known to differ in properties. An important survey of the soils of a large rubber estate in Malaya is now being made, one of our former workers being out there for the purpose; based on this survey is an extensive series of manurial trials. A comparison is being made of certain tropical and sub-tropical soils by some of these new methods to see how far the relations already found are likely to hold true generally.

This work will be facilitated by the investigations on the inorganic soil colloids now proceeding under E. M. Crowther. A new method has been worked out for the direct determination of aluminium in soil clays, and Sir William Bragg has kindly given facilities for using X-ray methods in the investigation of the clay structure.

Rare elements in plant nutrition. As for human beings and animals, so for plants, there are certain food substances which must be supplied, or normal growth does not take place. In one of the first investigations made by Miss Brenchley, at Rothamsted, small quantities of manganese were shown to be advantageous to cereals; later work by Samuel and Piper at the Waite Institute, Adelaide, showed that in its absence the oat plant is specially liable to "grey speck" disease. The Chemical Department is now engaged in a study of availability of manganese in deficient soils liable to this disease.

Miss Warington showed that small quantities of boron are needed, and from various parts of the world there have since come accounts of plant diseases associated with boron deficiency. The appearance of this deficiency is less rapid in spring and autumn than in summer, but plants require boron whatever the season. Some of the effects of reduced hours of daylight superficially resemble those of boron deficiency, e.g. both may prevent flowering, but the characteristic effects are entirely distinct. One result of lack of boron is to reduce the uptake of nutrients, calcium being more affected than either nitrogen or potash.

Fertiliser from waste coal. In recent years various humic substances have been prepared from waste coal for which fertiliser value might reasonably be expected. Careful tests of materials supplied by well-known experts in coal chemistry have, however, failed to reveal anything of value to the farmer. Claims of better success have been put forward in Germany, but so far we have no evidence that these are justified.

LUCERNE AND THE NODULE ORGANISMS

The demand for cultures of the nodule organism still continues satisfactorily, and we are informed by Messrs. Allen and Hanbury that enough were sold last year to treat seed for 4,200 acres.

Meantime, H. G. Thornton is continuing the study of the relations between the nodule bacteria and the plant. He finds that the infection of the host legume increases very greatly at the time when the true leaves open. At that stage the root hairs exude something which apparently causes the nodule bacteria in the soil to multiply; and, in turn, to produce something which causes the root hairs to curl; and at the bend thus made they enter. H. G. Thornton has now isolated from the bacterial products a gum which causes the root hairs to curl and also to grow, so that it is either itself a growth stimulating substance or it is associated with one. Its action, however, is neutralised by a small quantity of nitrate in the presence of which the root hairs remain straight so that the bacteria cannot enter, hence the well-known effect of nitrate in reducing the number of nodules or inhibiting their formation. This neutralising effect, however, is overcome by addition of a little sugar, suggesting that the carbon/nitrogen ratio, known to be important in other aspects of micro-organic life, is important here also.

SOIL MICRO-ORGANISMS

Some years ago it was shown that the number of bacteria in the soil is not constant, but varies from day to day, and even from hour to hour. Improved and more rapid methods of counting have now enabled this work to be extended by C. B. Taylor, and it is shown that the fluctuations still take place even when the temperature and moisture content of the soil remain constant : this confirms an older observation by D. W. Cutler. The fluctuations of the total number revealed by the direct staining method are of the same kind as those of the special groups that grow on the culture medium used in the plate method ; this is being further examined.

The respiration of different soil micro-organisms, as measured by oxygen uptake, is being studied in the Microbiology Department. The results are unsuitable for brief summary, but an interesting point brought out is that in young cultures the respiratory quotient (CO_2/O_2) is greater than 1, while in older cultures it is less than 1. The rate of oxygen uptake per 1,000 million cells reaches a maximum value about 60 hours after inoculation, whereas the rate of carbon dioxide output per 1,000 million cells is at its maximum in the first 24 hours after inoculation, and falls off as the culture ages.

An interesting survey was made by Miss Dixon of the protozoan faunas in the tobacco soils of South Russia. All the soil samples contained protozoa, even those taken at some depth below the surface, while the upper layers of the soil contained them in considerable numbers. There was, however, no relation between the protozoan fauna and the soil type. Variations in acidity have but little effect on the fauna, though the optimum pH value varies somewhat for the different species.

Perhaps the two most important actions of micro-organisms in the soil are the breakdown of the nitrogen compounds with production of nitrate and sometimes loss of nitrogen ; and the decomposition of the non-nitrogenous compounds to carbon dioxide and water, a change which either involves their complete disappearance or leaves a residue of humus. Both have been studied in detail in the Chemical, Microbiological and Fermentation Departments.

Both changes are much influenced by the ratio of carbon to nitrogen in the substances present. The amounts of nitrite and of nitrate formed are both less when the ratio is high than when it is low. The rate of decomposition of sugar is greater when the ratio is low, but as S. H. Jenkins shows, the rate of decomposition of cellulose is less affected, though it varies in the same way.

The changes depend on the nature of the nitrogen compound. In the decomposit on of straw, ammonia is taken up by the organisms rather than nitrate in the early stages of decomposition, but not in the later stages ; in the end both are equally utilised, though nitrate causes a greater loss of nitrogen. In the decomposition of

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sugar there is no evidence of any preference for ammonia over nitrate. The loss in presence of ammonia was about 14 per cent. with a C/N ratio of 8, but was nil, or even replaced by a slight gain, when the ratio was 84. Evidence is given that the loss of gaseous nitrogen takes place within the cell of the micro-organism and is not a simple decomposition of ammonium nitrate. There is also evidence that in presence of nitrate the loss is still greater, though no definite figures can yet be given.

Fungal tissue is fully available to micro-organisms as a source of nitrogen; it is as easily and as completely nitrified as ammonia and it left no resistant unnitrifiable residue.

In all these decompositions brought about by micro-organisms there is also much resynthesis, the organisms building up their body tissues out of the decomposition products.

The sticky part of the humic residue left in the decomposition of farmyard manure is supposed to have considerable physical effect in the soil; its formation has been studied in detail. It is most easily formed when the decomposition is begun by fungi and then carried further by bacteria; the optimum pH is about 9.5 or 10. Nitrate and fungal tissue are better sources of nitrogen than ammonia, and the action proceeds better when the mineral bases are sodium or potassium than when they are calcium or magnesium.

PURIFICATION OF EFFLUENTS

D. W. Cutler and E. H. Richards, and their staffs, are applying these results with considerable success to the purification of effluents from sugar beet factories and from milk factories. In both cases organic matter has to be decomposed and in both cases micro-organisms are far the cheapest agencies for doing the work. The conditions required are a ready supply of oxygen, suitable reaction and suitable carbon/nitrogen ratio. The requirements may vary at different stages in the decomposition: thus the decomposition of complex substances like proteins and fats proceeds most rapidly when the first stages are done under anaerobic, and the later stages under aerobic conditions.

For sugar beet factory effluents appropriate conditions have been worked out, and the results are embodied in a report issued by the Department of Scientific and Industrial Research, under whose aegis all this work has been done. For milk factory effluents the problem is proving more difficult because of the presence of fat; this is an old trouble long familiar to sewage experts, called upon to deal with the soap in domestic sewage. In view of its importance a special investigation of the decomposition of fat has been started. Conditions have been found under which both the fat and the casein can be precipitated from the effluent, leaving a liquid that can be run over biological filters without fear of clogging them.

PLANT PATHOLOGY

A new stage in the history of the Plant Pathology Department is opened with the appointment of J. Henderson Smith as Head and of G. Samuel as Mycologist in place of W. B. Brierley, and R. H. Stoughton respectively. Professor Brierley is writing his results for publication. Professor Stoughton's have been published, thus bringing to a close the work on Black Arm of cotton, the bacterial disease caused by *B. Malvacearum*, an investigation hitherto financed by the Empire Marketing Board. Miss Glynne has continued her work on Wart Disease of Potatoes and on Take-all (*Ophiobolus graminis*, Sacc) on wheat. The Wart Disease investigation is widened so as to include a study of some of the new varieties under examination at Ormskirk, a special grant being given by the Ministry of Agriculture for this purpose. A rapid method devised by Miss Glynne is used for distinguishing immune from susceptible varieties. This method, which needs only a few weeks for execution, gives results which agree in general with those obtained in the field after some two or three years trials ; it is therefore a great convenience to the potato breeder, because it shows him at once what material to discard and what to preserve. Miss Glynne finds an intermediate group of potato varieties which can be attacked by the disease organism, but which have the power of sloughing it off, so that it does no damage to the crop and causes no apparent loss in the field.

Miss Glynne also continued her survey of fungus diseases on the experimental plots, which is giving a mass of valuable observational data.

Thanks to action on the part of the Ministry of Agriculture, it has been possible to continue in full the investigations on Virus Diseases of Plants, hitherto financed by the Empire Marketing Board. No striking advance can be reported this year, but there has been a good deal of general progress as the result of much quiet steady work. In spite of many attempts, no method has yet been found of growing the virus outside the plant. The analysis of virus diseases has continued. A fourth "ring spot" disease of tobacco has been found, caused by a mixture of two separate viruses, neither of which alone can produce it. The aucuba virus of tomato, which has been in our laboratory for some time, is now shown to be a mixture of two which act differently and apparently are to some extent mutually inhibitory. The production of virus symptoms by a trace of molybdic acid and perhaps of other chemicals has been further followed up, as also has the part played by the insect that carries the virus from one plant to another.

A beginning has been made by J. M. Birkeland on the application to plant viruses of the serological methods so much used in animal pathology.

ENTOMOLOGY

The chief investigations in this Department are concerned with :

(1) The factors responsible for the variations in numbers of insect populations ;

(2) The causes of the attraction of insects to the plant that they attack ;

(3) Methods by which they can be kept in check.

In studying the variations in numbers of insects from time to time, C. B. Williams has arranged some ingenious lighted traps to take samples of the night flying insect population. The catches for each separate hour of the night are kept distinct, and records are taken showing the meteorological conditions throughout the night, including continuous records of rainfall, temperature, pressure, wind direction and velocity, humidity, cloudiness, and degree of brightness. Data are being amassed, but it is too early to discuss them as yet.

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H. F. Barnes showed that the infestation of wheat by the two blossom midges *C. tritici* and *S. mosellana* was much less than last year (0.6 and 1.4 per cent. kernel attack respectively against 5 and 10.5 per cent. in 1932), probably because of the earlier emergence of the midges which prevented them ovipositing on the wheat.

Some of H. F. Barnes' observations on wheat midges are summarised in Table 8.

TABLE 8.—Damage to Wheat by Wheat Midges : Broadbalk.

(*a*) By *Contarinia tritici* Kirby.

Per 500 ears wheat.	1927	1928	1929	1930	1931	1932	1933
No. of larvae ..	1,780	2,195	19,265	18,595	19,273	7,356	1,511
No. of lost grain ..	239	203	1,434	1,394	1,701	1,039	125
Percentage of grain attacked ..	0.95	0.79	5.9	5.9	6.4	4.9	0.65

	1928-9	1929-30	1930-1	1931-2	1932-3
Degree of Parasitism	9.5%	27%	53%	45%	73%

(*b*) By *Sitodiplosis mosellana*, Géhin.

Per 500 ears wheat.	1927	1928	1929	1930	1931	1932	1933
No. of larvae ..	715	2,043	587	3,746	6,027	3,114	319
No. of lost grain ..	541	1,486	434	2,760	4,032	2,260	273
Percentage of grain attacked ..	2.2	5.7	1.8	11.7	15.0	10.5	1.4

	1928-9	1929-30	1930-1	1931-2	1932-3
Degree of Parasitism	73%	43%	85%	85%	85%

The degree of parasitism of the gall midge ("button top" galls) on basket willows was much less than in 1932, being about 13 per cent., instead of 53 per cent., and the number of midges was considerably higher. The total number of midges and parasites obtained from the plants, however, showed no marked change.

Population of 500 galls of the midge *Rhabdophaga heterobia*.

Year.	Midges.	Parasites.	Midges and Parasites.	Percentage Parasitism.
1932 ..	1,480	1,662	3,142	53
1933 ..	2,810	428	3,239	13

H. C. F. Newton is studying the phenomena of oviposition by this insect on different willow species. The purpose is to find why the insect chooses certain species on which to lay its eggs ; why it avoids others, and whether the species preferred can be made distasteful. The phenomena of gall formation are also being studied. It appears that willows can be divided into three groups : those on which eggs are laid and galls formed ; those on which eggs are laid but no galls formed ; and those on which no eggs are laid.

A sawfly (*Pteronidea melanaspis*) behaves towards the different willow species in just the opposite way to the midge. This suggests that a chemical constituent of the leaf is concerned, and it is repellent to the one insect but attractive to the other. This work is being closely followed up.

A nematode parasite of a grass thrips (*Aptinothrips rufus*) is being studied by Miss Lysaght, and also an internal fungus disease of the same thrips ; so far the fungus has not been identified.

INSECTICIDES

The work has been chiefly concerned with insecticide plants. Those containing rotenone and the pyrethrins are most valuable because, although highly poisonous to insects, they are comparatively harmless to human beings and domestic animals. Curiously enough, rotenone is highly poisonous to fishes also. There is an increasing demand for this substance which, so far, cannot be made synthetically on the large scale; it therefore has to be extracted from plants.

Pyrethrum (*Chrysanthemum cinerariaefolium*) is a valuable insecticide, its flowers containing two important active principles—the pyrethrins I and II. Experiments are made in collaboration with the Plant Pathological Department of the Ministry of Agriculture to ascertain the effect of soil, season, manuring and other cultural operations on the yield of pyrethrin per plant and per unit area. The plant is perennial in habit, but requires a period of dormancy otherwise it gives poor yields of flowers; generally speaking the climatic conditions of this country appear to suit it better than those of tropical countries. The possibility of obtaining by cross-fertilisation new and more potent strains than the old ones is being examined.

Unfortunately, pyrethrum dusts quickly lose their efficacy when exposed to air and light. Methods have now been devised for partially overcoming this.

Two groups of tropical plants, *Derris* spp. and *Lonchocarpus* spp., contain rotenone as well as other insecticidal substances, and are included in the investigations. Some of this work is done in association with the East Malling Research Station and with the Department of Agriculture of the Federated Malay States: it is clear that Malay can produce excellent samples.

The increasing demand for rotenone and similar insecticides and the fact that the British Empire can supply the necessary plant materials either from the tropical or the temperate regions makes it very desirable that this work should be developed much more intensively than is being done at present. F. Tattersfield has struck a very valuable line of work and his results are being closely watched by insecticide makers at home and in the United States. With more assistance he could make much more rapid progress than is possible at present. Messrs. Geo. Monro kindly provide funds for a technical assistant, while a substantial subscription has recently come from the well-known firm of Messrs. S. B. Penick & Co., of New York. The Department is still understaffed and could work to much greater advantage if more funds were available.

BEES

The useful investigations carried out by D. M. T. Morland over the last eleven years on the technique of honey production are now bearing fruit, and his services are increasingly in demand among bee-keepers. Considerably more work has been done this year on the factors determining the rate of accumulation of honey in the hive, as measured by continuous weighing, and on internal economy of the hive, studied by closely watching the activities of marked bees in a glass hive. New and interesting observations are being made which are giving much valuable information about honey production, swarming, and other subjects of great importance to bee-keepers.

Hitherto no work has been done on bee diseases, but at the urgent request of a large number of bee-keepers these are now to be included in the programme. The bee-keepers have expressed their interest by the very convincing method of subscribing through the British Bee-Keepers' Association the sum of £250 a year for three years towards the cost of the work. The Agricultural Research Council, impressed by this keenness, have granted an equal amount, so that a bacteriologist has now been appointed to study the Foul Brood Diseases. H. L. Tarr, of the Universities of British Columbia, Montreal and Cambridge, commenced work on May 1st, 1934. The Rothamsted authorities have, on their part, provided a good-sized laboratory exclusively for Bee investigations. It is hoped that further support will be forthcoming, so that the laboratory may be fully used for the working out of the highly important and extremely fascinating problems associated with bees.

THE STATISTICAL DEPARTMENT

With the departure of R. A. Fisher to take up his new duties on October 1st, 1933, as Galton Professor of the University of London, the Department enters on a new phase of its existence. Professor Fisher's work at Rothamsted has revolutionised the science of statistics and the technique of biological experimentation, and agriculture must consider itself indeed fortunate to have had his especial attention for so long. His own account of his work is given below. It is with great pleasure that we are able to record that he has consented to remain an honorary member of the staff in a consultant capacity.

With the improvement in the quality of agricultural experimentation, and the spread of the new methods, the demands on the Department for analytical and advisory work are continually increasing. Mr. Yates, who succeeds Professor Fisher as Head of the Department, while following the lines laid down by his predecessor, is endeavouring to expand the agricultural side of the Department's activities so as to make the new methods available to stations which are still working on the old lines and in problems where they have not yet been applied. The technique of Animal Husbandry experimentation, for example, is far behind that of field crops ; and many stations both in this country and overseas feel the need of some central statistical advisory department to which they can turn for advice on the layout of experiments and the interpretation of results ; some, indeed, would appreciate the services of a computing office which could take the heavier part of the arithmetical work off their shoulders.

It would be impracticable and unnecessarily costly to urge that each Agricultural Institution or Department doing experimental work should have a trained Statistical Staff, though the larger ones certainly should be so equipped. The Department at Rothamsted has since its inception devoted considerable time to helping experimenters from other institutions. It has received a constant stream of workers from all over the world, often bringing with them their own data, and spending weeks, or months, in applying the new methods to them, or in discovering how to apply them to new problems.

It is gratifying to know that new field experiments laid down in most parts of the Empire and in many foreign countries follow very closely the methods devised in the Department; frequently the Department has assisted in the design of the experiment or the interpretation of the results. Many reports involving experimental data have been brought here for discussion and examination before final presentation to the proper authority. The work is handicapped by shortage of staff, and could be greatly extended at relatively little cost.

The work of the Department is expanding in another direction. As the quality of the experimental results improves, so do the collections of data obtained over a sequence of years merit more careful summarisation and critical examination. Much of this type of work is urgently necessary. Reference has already been made to the part played by the Statistical Department in the Field Plot work. All the other Departments, however, from time to time appeal to the Department for assistance in designing experiments, and for aid in dealing with the results when they are obtained.

THE CONTRIBUTIONS OF ROTHAMSTED TO THE DEVELOPMENT OF THE SCIENCE OF STATISTICS.

R. A. FISHER.

In 1919, the year in which the Statistical Laboratory was founded, the function of the statistician was understood to consist in the determination from the data presented to him of certain average values, more or less capable of scientific interpretation, and also by the use of quantities of the second degree, squares and products, of "probable errors" regarded as adherent to the averages obtained. The term averages in this expression is to be interpreted somewhat widely, as will be more fully explained, and any extensive body of data is capable of yielding an unending variety of such quantities. Exactly what averages to obtain from the data depends inevitably on what kind of information it is desired to elicit, and is to this extent not a statistical question. A comprehension of the arithmetical processes is, however, needed to ensure that the averages obtained shall be appropriate to the meanings which it is hoped to place upon them; moreover, extensive bodies of data usually contain information on points which were not in mind when the observations were made, and some knowledge is needed to determine what types of information are available, and by what methods they can be elicited.

As a very simple example, it was shown in 1921 (1) that when the two methods yield appreciably different results, it was preferable to calculate the relative growth rate of plants or animals, not as some plant physiologists had maintained, by means of a formula analogous to that of simple interest, but on one analogous to compound interest. Again, with a sequence of annual figures, of the type prevalent in economic and vital statistics, and in the records of meteorological observations, and the "classical fields" at Rothams-

(1) R. A. Fisher—"Some remarks on the methods formulated in a recent article on 'The Quantitative Analysis of Plant Growth,'" Ann. App. Biol., VII, 367-372.

ted, it was shown in the same year (2) that by means of a series of averages related to the temporal order of the sequence, the greater part of the slow changes, ascribable to soil deterioration, weed infestation, changes in variety or cultural practice, could be separated from the annual fluctuations, ascribable to weather variations and "experimental error," so as to enable these two classes of variation to be studied without serious mutual interference and confusion. The most extensive work of this class undertaken in the laboratory was the calculation of the average effects of meteorological factors such as rainfall and sunshine at all periods of the year, on the yield of crops grown on the classical fields. This was first done for rainfall and wheat (3), and later the method was applied to sunshine and wheat, to rainfall and barley, and more recently to rainfall and mangolds. A later series of papers is concerned with the experimental evaluation of the constants of formulae, expressing the increase in yield produced by successive additions of one or more fertilisers (4).

The interpretation of all such estimates, formed by the combination of inexact observations, requires that the discrepancies also should be taken into account. This is the purpose of the calculation of a probable error, or standard error, but recent research commencing with the work of "*Student*" in 1908 has shown not merely that the concept of a probable error is insufficiently exact for application to the small numbers of observations usually available from experimental work, but that it is possible in suitable cases to develop exact tests of significance from which the notion of a standard error may be eliminated, and in which it plays therefore only a formal part. Neither the theoretical nor the practical significance of this advance was readily appreciated, partly because academic statisticians were not aware of the serious decisions which experimenters must take on the basis always of limited data, partly because "*Student*" only treated an isolated and especially simple case, and it was not understood that the exact mathematical treatment of other more complicated cases arising in practical research was at all practicable. The work of developing exact methods appropriate to the actual nature of the experimental data is probably that aspect of the work of the statistical laboratory which is best known. This is partly due to the fact that many biologists were in a position to appreciate the advantage of introducing such methods as ancillary to their own studies, as is exemplified in (5); partly to the fact that the exact

(2) R. A. Fisher—"Studies in Crop Variation. I. An Examination of the Yield of Dressed Grain from Broadbalk." J. Agri. Sci., XI, 107-135; and later W. A. Mackenzie—"Studies in Crop Variation III. An Examination of the Yield of Dressed Grain from Hoos Field," Journ. Agric. Sci., vol. XIV, 1924, pp. 434-460; R. J. Kalamkar—"A Statistical Examination of the Yield of Mangolds from Barnfield at Rothamsted," Journ. Agric. Sci., vol. XXIII, part II, 1933. pp. 161-175.

(3) R. A. Fisher—"The Influence of Rainfall on the Yield of Wheat at Rothamsted," Phil. Trans., 213, 89-142; L. H. C. Tippett "On the Effect of Sunshine on Wheat Yield at Rothamsted," J. Agri. Sci., XVI, 159-165; W. A. Mackenzie and J. Wishart—"The Influence of Rainfall on the Yield of Barley at Rothamsted," J.Agri. Sci., XX, 417-439; R. J. Kalamkar—"The Influence of Rainfall on the Yield of Mangolds at Rothamsted," Journ. Agric. Sci., XXIII, Part IV, 1933. pp. 571-579.

(4) B. Balmukand—"The Relation Between Yield and Soil Nutrients," J. Agri. Sci., XVIII, 602-627; R. J. Kalamkar—"An Application of the Resistance Formula to Potato Data," J. Agri. Sci., XX, 440-454.

(5) R. A. Fisher.—"The Accuracy of the Plating Method of Estimating the Density of Bacteria Populations" (1922), Ann. App. Biol., IX, 325-359; "Statistical Study on the Effect of Manuring on Infestation of Barley by Gout Fly" (1924), Ann. App. Biol., XI, 220-235; "Tests of Significance in Harmonic Analysis" (1929), Proc. Roy. Soc., A, 125, 54-59; J. B. Hutchinson—"The application of the 'method of maximum likelihood' to the estimation of linkage" (1929), Genetics. 14, 519-537.

mathematical treatment of problems hitherto regarded as insoluble, opened a new field of study in mathematical statistics (6), which supplied the foundation upon which simple and exact practical procedures were based. Much discussion was naturally engendered by the fact that many procedures widely used and believed to be satisfactory approximations were found to be wholly misleading. As might be expected both mathematical statisticians, and biologists other than agronomists, whose work involves numerical tests, such as geneticists, entomologists, marine biologists, etc., have been strongly represented among voluntary workers.

Among types of data to which particular attention has been paid is that presented by series of annual figures, such as those obtained in meteorological records, drain gauges, and the classical experiments. This type of data, to which the bulk of official statistics belongs, has offered the greatest difficulty to economists and sociologists, and it was inevitable that such progress as had been made at Rothamsted in the development of methods of analysis should have attracted interest outside the sphere of agricultural science.

Although the solution of the problems of statistical distribution was primarily necessitated by the immediate requirements of practical research, it has brought with it theoretical consequences in the development of the mathematical theory of estimation. The best method of averaging, or of combining the observations, for any defined purpose, may be inferred from the nature of the errors to which different types of estimate are liable. The practical importance of this step is that it enables the computer to go ahead with confidence that he is getting the whole of the value out of the material being analysed. Its theoretical importance is that it gives the qualities of coherence and exactitude to the processes of inductive reasoning, by which conclusions of general application are deduced from particular observations (arguments from the sample to the population) ; while other branches of mathematics are applied only to deductive reasoning. A whole series of papers deals with this development (7).

Any sweeping theoretical advance, simply because it affects the way in which people are thinking of their problems, is likely to have unexpected consequences. One striking effect, due to a too close pre-occupation with academic ideas, rather than with the practical purposes for which these ideas were developed, is that the scientific interest of the subject is thought to be exhausted. It is, indeed, true that schools of thought, whose whole horizon has been occupied for a generation by problems of " curve fitting," should find themselves

(6) R. A. Fisher.—" On the ' probable error ' of a coefficient of correlation deduced from a small sample " (1921) Metron. 1 (4), 1-32 ; " The Goodness of Fit of Regression Formulae and the Distribution of Regression Coefficients" (1922), Jour. Roy. Stat. Soc., LXXXV, 597-612 ; " The Conditions Under which χ^2 measures the Discrepancy between Observation and Hypothesis " (1924), Jour. Roy. Stat. Soc., LXXXVII, 442-449 ; " The General Sampling Distribution of the Multiple Correlation Coefficient " (1928), Proc. Roy. Soc. A, 121, 654-673 ; " Tests of Significance in Harmonic Analysis " (1929), Proc. Roy. Soc., A, 125, 54-59 ; " The Moments of the Distribution for Normal Samples of Measures of Departure from Normality " (1930), Proc. Roy. Soc., A, 130, 16-28 ; " The Sampling Error of Estimated Deviates, Together with other Illustrations of the Properties and Applications of the Integrals and Derivatives of the Normal Error Function," Brit. Ass., Math. Tables, Vol. I (1931) (Introduction), pp. xxvi-xxxv.

(7) R. A. Fisher.—" A Mathematical Examination of the Methods of Determining the Accuracy of an Observation by the Mean Error, and the Mean Square Error " (1920), Monthly Notices of the Roy. Astrom. Soc. LXXX, 758-770 ; " On the Mathematical Foundations of Theoretical Statistics," Phil. Trans. Roy. Soc. London, A, CCXXII, 1922. Pp. 309-368 ; " Theory of Statistical Estimation," Proc. Cam. Phil. Soc., vol. XXII, 1925. Pp. 700-725 ; " Inverse Probability," Proc. Cam. Phil. Soc.. vol. XXVI, 1930. Pp. 528-535 ; " Inverse Probability and the Use of Likelihood " (1932), Proc. Cam. Phil. Soc., XXVIII, 257-261.

faced with vacuity, when the methods of estimation appropriate to any particular case can be set down at once by any novice who knows the theory ; but the fact remains that had curve fitting been regarded solely as a means to the practical purpose of eliciting the scientific facts derivable from the data, the predominant feeling would have been merely that a troublesome obstacle had been removed. The ground has at the same time been cleared of another misapprehension derived from the same source. In the period when highly inefficient methods of estimation were habitual, the amount of information extracted by the statistician depended largely on his personal skill and acumen. "High correlations," and significant results, when obtained, were displayed with some pride, as in some way implying personal competence. When, on the other hand, methods known to be fully efficient are used, the amount of information which the data are capable of yielding has also been assessed, and it is useless either to commend the statistician if it is much, or to reproach him if it is little. The statistician must be treated less like a conjurer whose business it is to exceed expectation, than as a chemist who undertakes to assay how much of value the material submitted to him contains. The idea of treating "amount of information" as a mathematical quantity, like the ideas of likelihood, and of intrinsic accuracy, is itself derived from the theory of estimation. An essential part of the statistician's task is how to evaluate the limitations of the data in hand ; as is stated emphatically by E. B. Wilson :

> We must expect that in many cases the statistical indications will lead us temporarily to abandon our problem because of a realisation of the fact that material adequate to its solution cannot be had.—*American Journ. of Cancer*, 1932.

The exhaustion of the task of improving on inefficient methods of calculation brings us at once face to face with the defects in experimental technique or in observational procedure, to which the intrinsic limitations of the data are due.

The work of this type to which the Statistical Laboratory has given most attention is the improvement of field experiments (8). At the time this work was started, it was customary to carry out the operations of field plot experimentation with great care as to the measuring of the land, separation and weighing of the crop, etc, without the experimental results attaining to anything like comparable precision. This was due to the heterogeneity of the soil, which was always found to be considerable, however much

(8) R. A. Fisher and W. A. Mackenzie—"The Manurial Response of Different Potato Varieties' 1923, Journ. Agri. Sci., XIII, 311-320 ; R. A. Fisher—"The Arrangement of Field Experiments," Journ. Min. Agric., vol. XXXIII, 1926. pp. 503-513 ; T. Eden and R. A. Fisher—"Studies in crop variation : IV. The Experimental Determination of the Value of Top Dressings with Cereals." Journ. Agric. Sci., vol. XVII, 1927, Pp. 548-562 ; T. Eden and R. A. Fisher—"Studies in Crop Variation : VI. Experiments on the Response of the Potato to Potash and Nitrogen." Journ. Agric. Sci., vol. XIV, 1929, pp. 201-213 ; J. Wishart and H. J. G. Hines—"Fertilizer Trials on the Ordinary Farm," Journ. Min. Agric., 1929, pp. 524-532 ; H. G. Sanders—"A Note on the Value of Uniformity Trials for Subsequent Experiments," Journ. Agric. Sci., vol. XX, 1930, pp. 63-73 ; R. A. Fisher and J. Wishart—"The arrangement of Field Experiments and the Statistical Reduction of the Results," Imperial Bureau Soil Science, Tech. Com. No. 10, 1930; F. E. Allan and J. Wishart—"A Method of Estimating the Yield of a Missing Plot in Field Experimental Work," Journ. Agric. Sci., vol. XX, 1930, pp. 399-406 ; J. O. Irwin—"Precision Records in Horticulture," Journ. of Pomology and Horticultural Sci., vol. IX, 1931, pp. 149-194 ; B. G. Christidis—"The Importance of the Shape of Plots in Field Experimentation," Journ. Agric. Sci., vol. XXI, 1931, pp. 14-37 ; F. R. Immer—"Size and Shape of Plot in Relation to Field Experiments with Sugar Beets," Journ. Agric. Res. 44, 1932, pp. 649-668 ; S. H. Justesen—"Influence of Size and Shape of Plots on the Precision of Field Experiments with Potatoes," Journ. Agric. Sci., vol. XXII, 1932, pp. 366-372 ; R. J. Kalamkar—"Experimental Error and the Field Plot Technique with Potatoes," Journ. Agric. Sci., vol. XXII, 1932, pp. 373-383 ; F. Yates—"The Analysis of Replicated Experiments when the Field Results are Incomplete," Emp. Journ. Expt., Agric. I, 1933, pp. 129-142.

trouble had been given to choosing a " uniform piece of land." In these circumstances subdivision of the experimental area into small replicated plots performed the double service of diminishing the experimental error, and of providing an estimate of the error that remained. The rationale and implications of this procedure were, however, for some time the subject of a certain amount of misunderstanding.

In the first place, whereas the object of diminishing the experimental error is much aided by replication, replication is only one of many methods of furthering this aim. Care in ensuring that in all points the experimental area is treated as in agricultural practice, the elimination of border rows, accuracy in seed rates, spacing, and measurement of the experimental area, as well as care in the separation, weighing and analysis of the produce, all make their contribution to the amount of information which the experiment finally gives. It is only when the " working errors " are reduced to unimportant quantities that soil heterogeneity becomes the major cause of error, and that greatly increased precision can be attained by improving the replication and arrangement of the experiment. On the other hand replication is the sole source of the estimate of error, by which the value and significance of the experiment is to be assessed. The estimate of error is not created by the statistician out of nothing, but is inferred from the observations by a process of estimation analogous to that used in the estimation of any other quantity, and requiring the same care in experimental design if the estimate is to be a valid one.

Owing to the fact, however, that the material conduct of an experiment had been regarded as a different business from its statistical interpretation, serious lacunae had been permitted between what had, in fact, been done, and what was to be assumed for mathematical purposes. In consequence methods of statistical analysis had been widely used, which gave definitely misleading estimates of error ; and, on the other hand, methods of field experimentation had been employed which were inherently incapable of yielding a valid test. It was necessary to treat the question of the field procedure, and that of statistical analysis as but two aspects of a single problem, and an examination of the relationship between these two aspects showed that once the practical field procedure was fixed, only a single method of statistical analysis could be valid, and, what was of more practical importance, that its validity depended on the introduction of a random element in the arrangement of the plots. The specification of the particular process of randomisation carried out, determined in advance the correct statistical analysis of the results. The logical structure of each of the possible types of randomisation is easily sorted out by the arithmetical arrangement known as the analysis of variance.

When not more than eight varieties, or treatments, or combinations of these are to be compared, a very complete elimination of the errors due to soil heterogeneity is possible by means of the Latin square, in which the number of replications is equal to the number of treatments, each of which appears once in each row and once in each column of the square. If, apart from this restriction, the plots are arranged at random, a valid and usually much diminished estimate

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of error is available, as was inferred theoretically, and later demonstrated experimentally by Tedin, on the basis of 92 uniformity trials (9) ; systematic arrangements in a square may give consistently either an over- or an under-estimate. A simple and more flexible arrangement adaptable to any numbers of treatments and replications is that known as randomised blocks, in which each block contains one plot of each treatment, these being distributed at random within it. Both these arrangements are now used all over the world with the exception of France, Italy, and parts of Germany, where other methods believed to be satisfactory had been previously adopted.

A very considerable advance in precision which has been demonstrated at Rothamsted, but has not as yet been so widely adopted abroad, is made possible by a factorial arrangement of treatments, so that if, for example, some plots receive phosphate and others none, these sets will be equal in number, and similar in the manurial and cultural contrasts within them. A large number such as 24 or 48 treatment combinations are thus tested simultaneously with comparatively little replication, the loss of which is made good by the inner or implicit replication, which the factorial arrangement makes possible. Thus though 48 such treatments may be replicated only 3 times, the whole information of 144 plots is available for every single contrast among the treatments tested, and equally for the differential effects of each treatment in the presence or absence of others. The increase in precision obtained by combining several different questions in the same experiment is due to the fact that, with a factorial arrangement, every plot contributes equally to answering each of them, whereas had 144 plots been distributed in 3 experiments for 3 separate questions there would have been only 48 plots available for each. A very important further advantage is gained by constructing large and complex experiments, beyond the gain of precision, namely that each question is examined in a considerable variety of subordinate circumstances, so that all results are given a much wider inductive basis than is possible with simple experiments. There have been examples of such factorial experiments at Rothamsted and Woburn since 1927.

A principle of undoubted value in the arrangement of field experiments, the practical possibilities of which are still being explored (10), consists in sacrificing information on interactions of subordinate interest, which it may often be confidently foreseen will be unimportant, by confounding them with soil heterogeneity, so eliminating a larger proportion of the latter from the more important comparisons. "Confounding" has been successfully employed in several experiments, and it is certainly capable of yielding for equal labour, a much needed increase in precision. It has, however, the real disadvantage, as has appeared on several occasions, that later workers, not realising the purpose and intentional limitations of the experiment, have been tempted to draw illegitimate conclusions involving the contrasts which have been

(9) O. Tedin (1931)— "The Influence of Systematic Plot Arrangement upon the Estmate of Error in Field Experiments," Journ. Agric. Sci., vol. XXI, pp. 191-208 ; F. Yates—" The Formation of Latin Squares for Use in Field Experiments," Empire Journ. Expt. Agric., vol. I, No. 3, 1933 pp. 235-244.

(10) F. Yates—" The Principles of Orthogonality and Confounding in Replicated Experiments," Journ. Agric. Sci., vol. XXIII, Part I, 1933, pp. 108-145.

deliberately set aside. With increasing knowledge of the principles of experimentation it will perhaps be possible to utilise its advantages more freely.

A great deal of attention has been given to experiments involving the particularly important and particularly intricate problems raised by residual effects, requiring repeated experimentation on the same land, and especially to evaluating such effects upon land under a normal agricultural rotation. It is possible to treat such experiments as replicated in time, and designed to eliminate errors due to temporal as well as local fluctuations. A four course rotation of 100 plots has been laid down to examine the availability of the nutrients in farmyard manure, in artificially rotted straw, and in straw rotted in in the ground, in addition to a comparison between superphosphate and rock phosphate, in the year of application and in subsequent years of the rotation. The experiment should also demonstrate whether or not the humus manures produce, relatively to artificial fertilisers, a gradual amelioration in the condition of the soil. A six-course rotation of 90 plots has been established, both at Woburn and at Rothamsted, with a view to assessing the seasonal fluctuations in the response of six crops to the three chief manurial nutrients. In this experiment all treatments progress continually over all the plots of the experiment, so that as time goes on, more and more of the soil heterogeneity is eliminated from the averages, and from other comparisons. A three-course rotation on a similar plan, involving both humus and green manures has now been laid down.

The department has been much concerned with the development of an adequate sampling technique, fit for studies in plant physiology, evaluation of damage due to insect infestation or plant disease, agricultural meteorology, yield determination, and the provision of qualitative samples for analysis (11). The key to this whole group of problems seems to lie in knowing how to sample the growing crop, with a precision known roughly in advance, and accurately determinable from the sample data. The official programme in agricultural meteorology has been much reduced, but sampling observations on wheat organised by the department are now carried out at eight centres (12), with the result that at these places at least there is someone who knows how to sample a crop in a reliable and comparable manner. The same principle has been later applied to the meteorological researches connected with forestry and horticulture. The method has been applied in a number of cases to experimental yields, and is especially useful where the plots have been sub-divided below the limit of economical harvesting by agricultural methods. Its other applications may be expected to develop as the possibilities

(11) A. R. Clapham—"The Estimation of Yield in Cereal Crops by Sampling Methods," Journ. Agric. Sci., vol. XIX, 1929, pp. 214-235 ; J. Wishart and A. R. Clapham—"A Study in Sampling Technique : The Effect of Artificial Fertilisers on the Yield of Potatoes," Journ. Agric. Sci., vol. XIX, 1929, pp. 600-618 ; A. R. Clapham—"Studies in Sampling Technique : Cereal Experiments : I. Field Technique," Journ. Agric. Sci., vol. XXI, 1931, pp. 367-371 ; T. W. Simpson—"Studies in Sampling Technique ; Cereal Experiments, II. A small-scale Threshing and Winnowing Machine," Journ. Agric. Sci., vol. XXI, 1931, pp. 372-375 ; A. R. Clapham—"Studies in Sampling Technique : Cereal Experiments. III. Results and Discussion," Journ. Agric. Sci., vol. XXI, 1931, pp. 376-390 ; R. J. Kalamkar—"A Study in Sampling Technique with Wheat," Journ. Agric. Sci., vol. XXII, 1932, pp. 783-792 ; F. R. Immer—"Study of Sampling Technique with Sugar Beets," Journ. Agric. Res. 44, 1932, pp. 633-647.

(12) Journ. Min. Agric., vol. XXXIX, No. 12 (March, 1933), pp. 1,082-1,084; vol. XL, No. 3 (June, 1933), pp. 206-208 ; vol. XL, No. 7 (October, 1933), pp. 591-593 ; vol. XL, No. 10 (January, 1934), pp. 903-906

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of the method, and the procedure of its correct execution, become better known.

The use of statistical methods in the design of experiments is, of course, applicable in laboratory as well as in field experiments, and the field technique developed is applicable to other than manurial problems ; many voluntary workers are concerned with these other fields of work, at home or overseas. By applying statistical methods not only to the interpretation but also to the design of experiments it is not uncommon for the value of the experiment to be increased five or tenfold, a result which could not be obtained from improved methods of interpretation only, unless previous methods had been excessively inefficient.

THE WOBURN EXPERIMENTAL STATION

Soon after the first period of fifty years of the Woburn Experimental Station terminated in 1926, the Royal Agricultural Society made a grant to Rothamsted to provide a special assistant in the Statistical Department for the purpose of working out the results. This has been done, and the Report is now being prepared for publication.

The outstanding results are as follows :

(1) Green manuring is not an infallible method of improving sandy soils : in the Woburn experiment it failed completely.

Experiments are now in hand to discover the conditions for success.

(2) The residual values of farmyard manure and of cake and corn fed to animals on the farm appear on this sandy soil to be much less than indicated by the recognised Tables.

This problem urgently needs following up : there seems little doubt that many farmers entering new farms are called upon to pay compensation for something that may never benefit them.

(3) Lime is urgently needed on this light sandy soil, as indeed on a large number of other light soils, but it is easily applied wastefully. Certain conclusions can be drawn as to the best way of using lime for different crops, but new experiments are needed to test them before they could be generally recommended.

(4) When cropped continuously by wheat or by barley the yields suffer marked deterioration whatever the manuring. Farmyard manure or heavy dressings of artificial fertilisers delay the setting in of the deterioration, but do not prevent it. This deterioration of yield is accompanied by a serious loss of organic matter in the soil, no less than one-third of the initial supply having disappeared from the plots that receive no farmyard manure. There is also a loss of exchangeable calcium which was intensified by the use of sulphate of ammonia and reduced by nitrate of soda. Superphosphate had no appreciable effect on the soil reaction, and even after fifty years of annual dressings there was no sign that acidity was being produced. Several causes appear to contribute to the deterioration in yield when one and the same crop is thus grown year after year on the same land. Weeds become very troublesome and, as in other experiments at Rothamsted, they exercise a particularly baleful effect on yield. Certain plant diseases, especially those associated with the

soil, tend to accumulate. The loss of carbon and nitrogen from the soil probably depresses productiveness.

It is not yet clear whether other crops such as market garden crops would suffer the same kind of deterioration, though observations on certain market gardens on the same kind of soil and not far away from Woburn suggest that this may be so. No method of recuperation has yet been tested. This of course brings us back to the old problem of soil sickness, which formerly received much attention at Rothamsted. The earlier investigations were with horticultural soils and the treatment adopted was partial sterilisation, which has now become general. For farm land, however, this method is unsuitable.

It seems evident that the subject should be re-investigated. One special aspect, clover sickness, has been studied in conjunction with T. Goodey of the Institute of Helminthology, St. Albans ; this work is still continuing.

(5) Although light soils are notoriously susceptible to drought we cannot find that either the wheat or the barley has suffered through lack of actual rainfall. A dry spell at a critical time may of course do harm, but over the fifty years there was no evidence of any uniform injury caused by dry weather. In 1933 in spite of the record drought, the annual rainfall being 17.8 inches only, we obtained on the light land at Woburn over 60 bushels of barley, 30 bushels of wheat, 14 tons of sugar beet and 8 tons of potatoes without excessive manurial treatment.

(6) The experiments show the conditions under which malting barley may be produced on a light soil.

(7) The acid plots have enabled us to study in detail the effects of acidity on plant growth, with the purpose of recognising the symptoms that appear before yields begin to suffer, and when therefore dressings of lime would be most advantageous and economical.

INSECT PESTS AT ROTHAMSTED AND WOBURN, 1932-3

H. C. F. Newton

General. The year was notable for very severe attacks : (1) on sugar beet by the Bean aphis, *Aphis rumicis* L. (plentiful also on the surrounding beans), (2) on kale by Flea-beetles (*Phyllotreta* spp.) in numbers sufficient to necessitate resowing, for the first time since 1930, (3) on barley by the Gout Fly, *Chlorops taeniopus* Meig. Damage by pigeons is increasing, and a large area of kale on Great Knott was stripped of its foliage when the plants were some six to eight inches high.

Broadbalk. *Wheat.* There was no winter attack by Frit Fly but some loss of plant by soil insects occurred during the winter months. Wheat Bulb Fly (*Hylemyia coarctata* Fall.) did not cause appreciable damage, though many tillers were destroyed ; the attacked tillers on the fallowed plot were about twenty times more numerous than those on the unfallowed. Wheat Leaf Miner (*Agromyza* (*Domcmyza*) *ambigua* Fall.) was rare; Wheat Midges (*Contarinia tritici* Kirby, *Sitodiplosis mosellana* Géhin) were notably less abundant, the figures for the last seven years being :

Year	1927	1928	1929	1930	1931	1932	1933
Percentage grain attack	3.2	6.5	7.7	17.6	21.4	15.4	2.1

https://doi.org/10.23637/ERADOC-1-3

Hoos Field. Four Course Rotation. *Barley* suffered an unusually severe attack of Gout Fly ; Wheat Bulb Fly was generally present on the wheat, but the Leaf Miner was rare. The classical barley plots were fallowed.

Barnfield. *Mangolds.* An attack by *Atomaria linearis* Steph. the Pigmy Mangold Beetle, reduced the plant on certain areas, notably the 4N, 5N, 6N, 5A and 6A plots. *Bourletiella hortensis* Fitch, the Mangold Springtail, was also responsible for some loss of seedlings, especially on the northern side of the field. Damage by birds again occurred in a semi-circular area around the poultry experiment (chiefly plot 1AC) extending outwards some twelve rows. The damage consists in the loss of both cotyledons at an early stage before the second leaf appears, so that such as survive remain stunted. *Plectroscelis concinna* Marsh and *Pegomyia hyoscyami* Panz. were not seen.

Great Knott. *Kale* (*second sowing*). The first serious outbreak of Flea-beetles (*Phyllotreta* spp.) since 1930 destroyed the entire plant of the second sowing of kale. The species concerned were *P. undulata* Kuts. 50 per cent., *P. nemorum* L. 20 per cent., *P. atra* 14 per cent., *P. diademata* Foudr. 11 per cent., *P. vittula* Redt. 4 per cent., *P. nigripes* F. 1 per cent. The kale was sown on May 16th and was attacked during the last week in May and the first week in June ; the Flea-beetles spread across the field from the direction of Knott Wood—from south to north. Areas were sprayed with a hand atomizer using (1) paraffin and (2) a paraffin—pyrethrum extract, at a rate of one gallon to the acre. Two sprayings were given, but without ultimate effect. Atomized paraffin has been claimed in the past to be very successful as a repellent for these beetles. A difficulty with small areas is that the wind tends to drift the atomized spray, and it is possible that the complete treatment of the field would be more successful. No marked benefit resulted from the addition of the pyrethrum extract.

The kale was resown on 26th June. Except for slight damage on the most southerly rows it was untouched ; and in spite of the drought a reasonable crop was obtained.

First Sowing. On part of the field the kale had been sown earlier (26th April). This area escaped serious damage as the plants were well established in the cotyledon stage when the Flea-beetles appeared. *During the year the field was an excellent illustration of the importance of early sowing in connection with Flea-beetle attack.* This plot was later subject to severe damage by pigeons, the majority of the plants, when about 6 ins. high, being stripped of their assimilating tissue.

Long Hoos. Six Course Rotation. *Sugar-beet.* A good "plant" was not seriously affected either by Springtails or the occasional *Plectroscelis concinna* Marsh that were present. The gappiness occurring later which necessitated some transplantation was only partly due to wireworm attack. Bad growing conditions were chiefly responsible and the plants " went off " with a blackening of the root resembling " Black Leg " symptoms. A heavy infestation of *Aphis rumicis L.*, the Bean Aphis, followed, which together with the drought, brought growth to a standstill. On 17th August the whole plot had a yellowed appearance due to the effects of the aphis on the outer leaves. These leaves were now encrusted on their under-sides with dead aphides and a mould-like fungus—the latter probably being instrumental in bringing the infestation to an end.

Barley. Considerable gapping of the plant at the end of April was caused by wireworm, but there was less Gout Fly than elsewhere.

Wheat and *Forage Mixture* suffered from wireworm attack in the early spring. *Sitona lineata* L. attacked the few beans left in the forage mixture ; some of the oats were affected with a kind of " whitehead " due to the stem being ringed by an unidentified agent.

THREE COURSE ROTATION. *Sugar beet* suffered from Bean Aphis, but less so than the Six Course Rotation ; rabbits destroyed occasional plants.

Barley. Wireworm attack continued during April and May, and was followed by an infestation of Gout Fly considerably above the normal.

Oats. Wireworm caused many bare patches in the oats in series III and II.

PASTURES. The barley experiment was attacked by wireworm in April-May, causing an uneven plant ; on the wheat experiments the damage done by this insect was not significant.

Sugar Beet. No serious damage to the " plant " was caused by insects though an occasional wireworm was found. As in the rotation experiment, however, a large number of seedlings showed a blackening of the root and remained stunted—many eventually dying off. The striking difference in size between such plants and those unaffected was to be seen over the whole experiment. The symptoms could not be ascribed to insect attack, and though resembling those of Black Leg, were probably a drought effect. An attack of *Aphis rumicis*, less severe than on Long Hoos, followed.

GREAT HARPENDEN. *Brussels sprouts*. Early in the season some loss of plant was caused by hares or rabbits and by *Chortophila* (*Hylemyia*) *brassicae* Bché, the Cabbage Root Maggot. In the autumn and winter months a general but not severe attack of the Mealy Cabbage Aphis, *Brevicoryne brassicae* L. occurred. Only about 10 per cent. of the plants were infested to any extent, and of these only a third were badly infested. Syrphid larvae and Hymenopterous parasites were present, but the parasitisation was low. Three parasites were bred out. They were the Braconid *Aphidius brassicae* Hal, the Chalcid, *Asaphes vulgaris* Nees (=*aeneus* Walk.) the Cynpid, *Allotria brassicae* Ashm., the figures relative to Aphid numbers being 15 per cent., 8 per cent., 1 per cent., respectively. Of these the first is the only effective figure, as the two other insects are probably hyperparasites. These figures are extremely low—as the aphid is often parasitized 100 per cent.

Cabbage White Fly (*Aleurodes brassicae* Walk.) was plentiful during the same period.

Barley. Gout Fly severely attacked the crop, every third tiller of a number of plants examined being affected.

FOSTERS. *Wheat*. Wheat Bulb Fly was generally present. Thrips were unusually plentiful in the summer here, as on the other cereals.

LITTLE HOOS AND LONG HOOS. *Beans*. Attack by *Aphis rumicis* L.

WOBURN

The farm at Woburn was inspected on June 16th, but no serious insect damage was seen.

FUNGUS DISEASES AT ROTHAMSTED AND WOBURN, 1932-33

MARY D. GLYNNE

WHEAT

Mildew (*Erysiphe graminis* DC.) was slight by July on most of the wheat crops under observation. It was moderate on some plots of Broadbalk and on the Woburn Six Course Rotation, and varied from absent to plentiful on different parts of the Six Course Rotation on Long Hoos and the Commercial Wheat on Fosters.

Whiteheads (Take-All) (*Ophiobolus graminis* Sacc.) was found on wheat grown continuously or in alternate years on the same land, and was much more plentiful on the light land at Woburn than on the heavier land at Rothamsted. On wheat grown alternately with green manure on Stackyard and Lansome fields at Woburn the disease was moderate, reaching a maximum of about 13 per cent. plants infected. On certain plots of the Continuous Wheat, Stackyard field, as many as 43 per cent. of the plants were infected at harvest. Plots with a high soil acidity (pH below 5) were practically free from the disease. A detailed survey carried out since 1931 showed an increase in percentage diseased plants from 1931 to 1932 on all plots affected by the disease. In the following year there was an increase in infection in all plots numbering seven which, in 1932 had less than 35 per cent. infected and a decrease in infection in the seven plots which had 35 per cent. or more of their plants infected in 1932. The significance of this observation is not yet clear.

Loose Smut. (*Ustilago Tritici* (Pers.) Jens.) was rare except on certain blocks of the Precision Wheat on Lansome field at Woburn.

Brown Rust (*Puccinia triticina* Erikss.) was slight in July on most of the Wheat and was moderate on the Commercial Wheat on Fosters field and the Cultivation experiment on Pastures.

Yellow Rust (*Puccinia glumarum* (Schm.) Erikss. and Henn.) appeared in June and varied from slight and moderate to plentiful at Rothamsted, while at Woburn it was never more than slight.

Foot Rot (*Fusarium* sp.) was occasional on Broadbalk, slight on the Alternate Wheat and Green Manure experiment on Stackyard and a little more plentiful on the Green Manuring experiment on Lansome field, Woburn.

Leaf Spot (*Septoria Tritici* Desm.) of little if any economic importance, was found occasionally.

OATS

Mildew (*Erysiphe graminis* DC.) was generally slight except on the Forage oats grown on Pastures field, where it was plentiful.

Leaf Spot (*Helminthosporium Avenae* (Bri. and Cav.) Eid.) was slight on all oat crops grown at Rothamsted. None was grown at Woburn.

BARLEY

Mildew (*Erysiphe graminis* DC.) varied from slight to plentiful on different crops at Rothamsted, and was rare at Woburn.

Whiteheads (Take-All) (*Ophiobolus graminis* Sacc.) is more common on wheat than on barley, on which it was found only on the Continuous Barley experiment on Stackyard field, Woburn. A detailed survey showed a variation in different plots of from 0 to 15 per cent. plants infected. As in the case of wheat, little or no disease appeared in plots with a high soil acidity (pH below 5).

Net Blotch (*Pyrenophora teres* (Died.) Drechsl.) varied from rare to moderate at Rothamsted, and was not recorded at Woburn. In the preceding year it was much more common and was found on all the barley crops, being plentiful in several of them.

Brown Rust (*Puccinia anomala* Rostr.) varied from slight to moderate at Rothamsted and was slight at Woburn.

Leaf Stripe (*Helminthosporium gramineum* Rabenh.) was found on all the barley crops, and varied from slight to moderate at Rothamsted and slight to plentiful at Woburn. There was more on the Six Course Rotation at Woburn than at Rothamsted. Infection seemed to be mostly secondary, and did not kill the plants.

Leaf Blotch (*Rhynchosporium Secalis* (Oud.) Davis), which is usually found on several of the barley crops, could not be found this year.

RYE

Brown Rust (*Puccinia secalina* Grove). Occasional spots of Brown Rust were found at Woburn on the Six Course Rotation, but none at Rothamsted.

Leaf Blotch (*Rhynchosporium Secalis* (Oud.) Davis) was moderate on rye mixed with vetches on the Six Course Rotation at Rothamsted and Woburn.

GRASSES

Ergot (*Claviceps purpurea* (Fr.) Tul.). None could be found, though it had been common in the previous season on a number of wild grasses left to ripen between fields and on the edge of plots.

GRASS PLOTS

Choke (*Epichloe typhina* (Fr.) Tul.), which was found chiefly on Agrostis and much less on Dactylis glomerata, appeared to have remained fairly constant over the four years in which eye estimations were made, 1930-33, except that after the addition of lime in 1932 there was a decrease in disease from slight to absent in the least acid plots. As before, the disease was most plentiful on plots which had received Ammonium Sulphate, and was less on those which had received lime. The disease was plentiful only on fairly acid plots (pH 5.5 or less). Agrostis was also most plentiful on these plots. The fungus was in many instances attacked by the larva of a small dipteron *Anthomyia spreta*, Meig., which lays its eggs on the surface of the fungus stroma.

CLOVER was mostly grown in forage mixtures and was unusually free from disease.

Downy Mildew (*Perenospora Trifoliorum* de Bary) was slight on Lansome field, Woburn.

BROAD BEANS

Chocolate Spot (*Bacillus Lathyri* Manns and Taubenh.) was plentiful on Little Hoos, and moderate on Long Hoos.

Grey Mould (*Botrytis* sp.) was plentiful in July on both fields, killing the leaves, so that by mid-July about 20 per cent. of the plants on Long Hoos appeared dead.

Rust. (*Uromyces Fabae* (Pers.) de Bary) was very slight.

POTATOES

(Variety Ally.) All the potatoes appeared healthy in June and July. At Rothamsted the tops, however, died early, possibly owing to the dry season.

Stem Canker (*Corticium Solani* Bourd. and Galz.) was moderate on Butt Furlong in the Six Course Rotation at Woburn.

Black Leg (*Bacillus phytophthorus* Appel) was rare; only one affected plant was found at Woburn.

SUGAR BEET

On the whole very healthy.

Black Leg. A little was found on Pastures Field, Rothamsted, and on Lansome field, Woburn.

MANGOLDS

Black Leg. Early in June blackened main roots were detected in some of the young seedlings.

Mosaic (possibly Virus). A leaf Mosaic was very common on the mature crop and varied in incidence from 3 to 70 per cent. on different plots. It was clear that the disease had spread from centres of infection, advancing apparently independently of manurial treatment from one plot to the next. In general the plots receiving nitrogen were much more affected than those without, but there was little Mosaic on the dunged plot next to the no-nitrogen strip. Evidence is inconclusive as to how far the distribution of the Mosaic is fortuitous.

SWEDES

Brown Rot (Physiological or Bacterial). The crop appeared healthy till the autumn, when it was found that about 30 per cent. were affected by internal browning.

FARM REPORT, 1933

Weather.—The outstanding feature of the year October, 1932, to September, 1933, was the abnormally hot and dry weather. The total rainfall was only 22.48 inches, compared with the 80-year average of 28.70 inches. The two periods in which the droughts were most severe were the three winter months November, December and January, when only 4.488 inches fell as against the average of 7.760 inches; and the five summer months April to August, when only 5.629 inches fell, less than half the 80-year average of 11.685 inches. This seriously affected the growth of late spring crops and of grass. October, with 4.842 inches, was 1.783 inches above the average, making the conditions very unfavourable for root-lifting. The break in the drought in September helped the kale crop and the grassland considerably, but the rain was too late to help the root crops.

The total sunshine for the year, 1,812 hours, was 255 hours above the 40-year average, and of this excess, the four months June to September yielded 170 hours. March gave the biggest monthly increase of 80 hours. The only months showing a decrease of more than 4 hours were November and May with 18 and 34 hours deficit, respectively.

The mean temperature for the year was nearly 2°F. above the normal of 48°F., the mean for every month except October and January being above the 55-year average. The warmest months were March, July, August and September, while January was cold and dry.

Effect of weather on crops

The remarkably hot and dry season had a depressing effect on the growth and subsequent yields of all crops other than corn crops.

The kale in Great Knott made very little growth during the summer months, most of the growth being made after the break of the drought in September. The yield was only about 15 tons per acre instead of the usual yield of about 25 tons per acre.

There was a marked increase in the percentage of seed and chat potatoes on all the potato experiments, with a resultant low total yield. Two strips of non-experimental potatoes which had received a dressing of dung yielded a normal crop of about 8 tons per acre.

The sugar beet remained stunted throughout its growth and the yields were very low. This was due to the small size of the roots produced and not to a lessened number of plants. The dung which was dug into the sugar beet microplots on Pastures field hardly decomposed at all, for at lifting time it appeared in much the same condition as when it was applied.

Park Grass plots yielded only one crop of hay instead of the usual two crops, and the one crop was below the average yield from all plots. In Agdell field seeds sown under barley made very little growth. The ground was ploughed up and sown with spring beans in 1934. The seeds in the 4-course rotation gave a poor yield, while the clover in the 6-course rotation failed completely and was ploughed up and sown with tares.

The farm hay crop failed almost entirely, but this was partly due to the fields being grazed until quite late in spring before being shut for hay. The grazing land also suffered badly and no growth took place after the end of June. By July many of the fields presented a very brown and parched appearance and additional feeding had to be given to some of the stock. The topping of the pastures seemed to have a detrimental rather than a beneficial effect, owing to the dry period immediately following this operation. The attempt at measuring the feeding values of grass mixtures in Sawyers I had soon to be abandoned.

All corn crops were well up to the average, wheat yielding an average of about 23 cwt., oats 18 cwt., and beans 20 cwt. per acre. Conditions were ideal for harvesting, and much of the corn was not stooked, but was threshed straight from the field. The corn crops ripened earlier than usual. Harvesting commenced on July 25th, and was finished by August 21st. The crops were also of better quality than they have been for the past few seasons, the barley being sold instead of being fed to pigs, as is usual.

The early harvest and suitable weather conditions were ideal for autumn cleaning operations, and several of the fields were shallow ploughed with the tractor immediately after harvest.

Cropping, 1932-33.

Dung was applied to Great Knott for kale this year, at 20 tons per acre. The eastern 8 acres were dunged and down with rye in autumn and folded off with sheep in April, while the rest of the field was stubble cleaned in autumn and dressed with dung in spring. Drilling took place on April 26th, 2 cwt. of sulphate of ammonia being applied before drilling and 1 cwt. as a top dressing in June.

The seedlings on a large part of the field were badly damaged by flea beetle and had to be resown. The plants on the part which was left were rather thin and had to be hand-hoed to keep down weeds until the kale grew away. One of the great advantages of kale is that hand-hoeing is unnecessary if a good plant is established, and if much hand-hoeing has to be done much of the advantage of kale over other root crops is lost. An experiment carried out on the farm in 1932 showed that both thinning and intensive inter-row cultivation of kale significantly reduce the yield of green material. The part of the crop which was affected most by the flea beetle was that following the rye folded off, and this was probably due to the difficulty in obtaining a suitable tilth for the small seeds after the folding.

Beans were sown in Little Hoos field after spring oats, in Long Hoos V after wheat, and in Long Hoos VII afte1 sheep keep. The crops in Little Hoos were very irregular and that after wheat was remarkably poor, but after the folded green crop a good yield was obtained.

Most of Pastures field was devoted to experiments on potatoes, sugar beet, wheat, barley and forage. Victor wheat was sown on the 4 acres nearest the wood after pigs had run over the bean stubble of last year's crop.

Two small strips of non-experimental potatoes were grown in Long Hoos IV and Pennel's Piece. Both these strips were dunged and were planted with Dunbar Cavalier potatoes. The crop was good considering the dry year, and the quality, from the culinary point of view, was well above that of the Ally used for the experiments. The better price obtained for the Dunbar Cavalier reflected this difference in quality.

Sections 1, II, III of Long Hoos were sown with Marvellous spring oats and undersown with Westernwolth's ryegrass and trefoil. The yield of oats was not very high, but the quality was good.

Foster's field was sown with Victor wheat and the southern half was undersown with Westernwolth's ryegrass and trefoil. The wheat was an excellent crop of good quality. The undersown seeds made almost no growth owing to the heaviness of the wheat crop, the late seeding and the dry season.

Great Harpenden field contained three crops. Eight and a half acres were under Plumage Archer barley, 2 acres under linseed and 2 acres under brussels sprouts.

Nearly every field on the farm is at present heavily infested with wireworm, which is causing great damage to the crops. Investigations are to be commenced into possible methods of control and eradication.

Classical and other Experiments

Broadbalk was sown on October 18th, section V being fallowed. The wheat grew well despite the season, and ripened about a fortnight earlier than usual. It was cut by July 28th, and the field was immediately tractor-ploughed. The effect of the previous year's fallow on Section II was very marked, but Section I, in its second year after fallow, appeared no better than the other sections.

Barnfield, after an early winter ploughing, worked down to a nice tilth and was sown on April 13th. Germination was slow, and the plants made little headway during the summer. The final yield, however, was better than was at one time expected. Carting conditions were rather unfavourable, but the land was ploughed up immediately afterwards to benefit from the winter frosts.

Hoos field barley plots were fallowed this year preparatory to returning to the narrow spacing of rows and the one variety of seed. For the past four years the barley has been sown in rows 18 inches apart, two varieties of seed being used. The wide spacing enabled the weeds to be kept in check, but with the return to the narrow 6 inch spacing after only a one year's fallow, it is doubtful whether the cleaning effect of the fallow will persist long. Plumage Archer will be the variety sown next year.

A new 3-course rotation (potatoes, barley, sugar beet) has been started in Long Hoos VI to compare the effects of ploughing in chaffed straw with straw rotted by the Adco process. The effect of two different green manuring crops ploughed under in spring is being compared with no winter cropping. This experiment should prove of great interest, for it will show to what extent the fertility of the land can be maintained by straw and artificials, and under what conditions green manuring gives the best results.

Market gardening crops were introduced into the experimental programme this year for the first time, the crop under test being Brussels sprouts. Dried poultry manure was tested against sulphate of ammonia for its nitrogen effect, and against superphosphate for its phosphate effect. The plants were put in during a rather dry period and had to be watered in. The average yield of about 30 cwt. per acre is considered quite satisfactory. Poultry manure was also tested on several other crops.

Livestock

Pigs. The chief development with livestock has been the establishment of a set of pig pens to develop a technique of an animal experiment that satisfies the requirements of modern statistical analysis. There are three blocks each containing three pens. Each pig is fed individually on its own ration by an arrangement of trough enclosures, one for each pig, leading from the main pen. This enables all types of ration to be distributed equally over all the groups of pens instead of all the pigs on one treatment being in the same pen. Any peculiarity of a group is thus distributed equally over all the rations instead of being associated with one particular ration.

Cattle. In October, 1932, the stock consisted of 7 cows and 100 crossbred store cattle and calves. The cows are put to a polled Angus bull, and the policy of buying in other black polled calves to put on to the cows as they calve has been continued. In the year October, 1932—September, 1933, over 60 calves were reared. For the first winter after weaning the calves remain in covered yards, and the second winter is spent out. They are usually finished off on grass in summer.

Sheep. The experimental programme commenced in 1931 has continued along the same lines. In the autumn of 1932, we put 49 of our home-bred Half-bred ewe lambs to the tup, and of these only 13 lambed. The rams used were a Southdown and a Half-bred ram lamb. It remains to be seen whether the ewe lambs which reared lambs will prove better mothers in future.

The result of the first lambing (1933) of the Dorset Horn cross Cheviot gimmers is given in the 1932 Report. We were not successful in getting these gimmers to take the Dorset Horn ram during the summer, but the same ram will again be run with them in the summer of 1934.

All the ewes and ewe lambs possessing four well-developed teats were again put to a ram with the same characteristic. A ram lamb of our own breeding was used this year, as the progeny of the two rams descended from the Bell flock were weakly and of poor conformation.

The result of the 1933 flushing experiment appeared in the 1932 Report. In the autumn of 1933, another experiment on the same lines was commenced. Any differences between the treatments will not be seen until the 1934 lambing, and the results will appear in the next Report.

Staff

E. C. Wallis came in December, 1933, as a voluntary assistant, and has now been transferred to the staff as Farm Recorder. J. T. Moon was here for a short time in the summer as voluntary worker to help with the livestock experimental work, and has since obtained a post in Kenya.

At the local ploughing match our two horsemen, F. Stokes and A. Lewis, secured 2nd and 3rd prizes respectively for their work.

METEOROLOGICAL OBSERVATIONS

Meteorological observations have been systematically made at Rothamsted for many years; these records are being used in the Statistical Department in interpreting crop records. The Station has co-operated in the Agricultural Meteorological Scheme since its inauguration by the Ministry of Agriculture in 1926, and possesses all the equipment required of a Crop-Weather Station. The observations taken under this scheme include :

Observations taken once daily : 9 a.m. G.M.T.

Temperatures—maximum and minimum (screen), solar maximum, grass minimum.

Rain (inches) and *Sunshine* (hours and minutes by Campbell-Stokes recorder) during the previous 24 hours.

Observations taken thrice daily : 9 a.m., 3 p.m., and 9 p.m. G.M.T.

Temperatures—wet and dry bulb (screen), 4 inches and 8 inches under bare soil.

Wind—direction and force (continuously recording anemobiagraph).

Weather—(Beaufort letters).

Visibility.

These, together with notes and observations of crop growth are used in drawing up the weekly statement for the purpose of the Crop Weather Report of the Ministry of Agriculture.

Additional data are collected under the following heads :

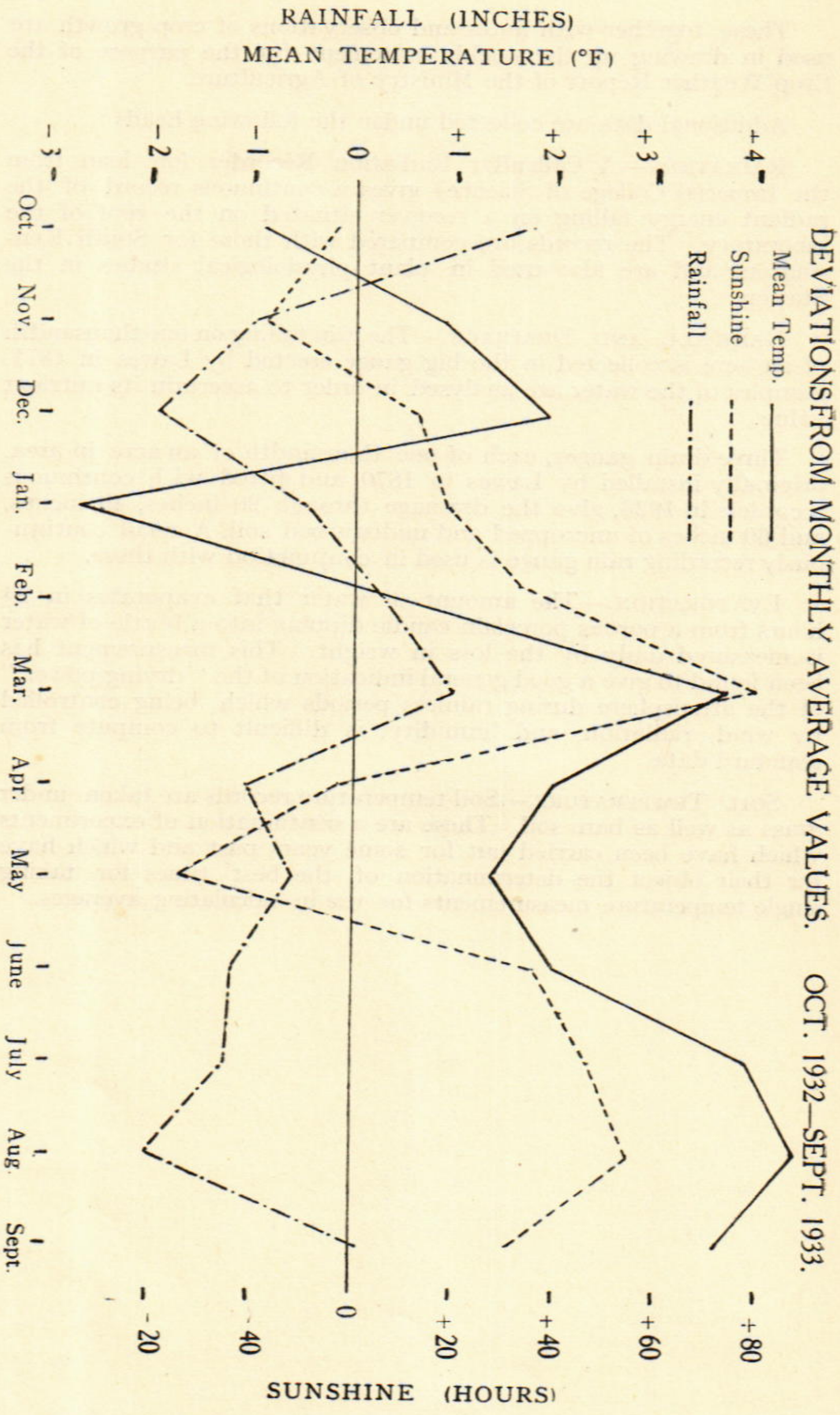
RADIATION.—A Callendar Radiation Recorder (on loan from the Imperial College of Science) gives a continuous record of the radiant energy falling on a receiver situated on the roof of the laboratory. The records are compared with those for South Kensington, and are also used in plant physiological studies in the Station.

RAINFALL AND DRAINAGE.—The rain falling on one thousandth of an acre is collected in the big gauge erected by Lawes in 1871. Samples of the water are analysed in order to ascertain its nutrient value.

Three drain gauges, each of one thousandth of an acre in area, originally installed by Lawes in 1870, and fitted with continuous recorders in 1926, give the drainage through 20 inches, 40 inches, and 60 inches of uncropped and undisturbed soil. A small continuously recording rain gauge is used in conjunction with these,

EVAPORATION.—The amount of water that evaporates in 24 hours from a porous porcelain candle dipping into a bottle of water is measured daily by the loss in weight. This measurement has been found to give a good general indication of the " drying power " of the atmosphere during rainless periods which, being controlled by wind, radiation, and humidity, is difficult to compute from standard data.

SOIL TEMPERATURE.—Soil temperature records are taken under grass as well as bare soil. These are a continuation of experiments which have been carried out for some years past and which have for their object the determination of the best times for taking single temperature measurements for use in calculating averages.



RAINFALL (INCHES)
MEAN TEMPERATURE (°F)
DEVIATIONS FROM MONTHLY AVERAGE VALUES. OCT. 1932—SEPT. 1933.
Mean Temp
Sunshine
Rainfall
+4
+3
+2
+1
0
-1
-2
-3
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
+80
+60
+40
+20
0
-40
-20
SUNSHINE (HOURS)