Report for 1931

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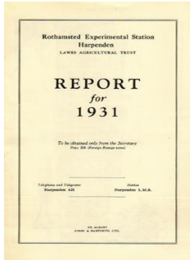
Rothamsted Experimental Station
Harpenden

REPORT
for
1931

Rothamsted Report for the Year 1931

Rothamsted Research

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REPORT ON THE WORK OF THE ROTHAMSTED EXPERIMENTAL STATION DURING THE SEASON 1931

The purpose of the work is to obtain information about the soil and the growing plant, and to put this information in a form in which agricultural experts and good farmers can use it. The work is done partly in the laboratory, partly in the pot culture house, and partly on the two experimental farms, the heavy land at Rothamsted and the light land farm at Woburn.

Broadly speaking, the laboratory work is concerned with the acquiring of information, while the field work aims at testing the applicability of this information on the farm and also at finding solutions for important practical problems of present-day agriculture.

THE FIELD EXPERIMENTS

The Conferences held at Rothamsted, and the visits made by members of the Staff to farms in different parts of the country, show that certain general problems are of great importance to large numbers of farmers: these are studied in the field.

(1) The most efficient use of artificial fertilisers on grass and arable land.

(2) The provision of keep for animals when grass supplies fall short.

(3) The maintenance of soil fertility in regions where mechanization is advancing and live stock is being reduced.

THE EFFICIENT USE OF FERTILIZERS

I. Grassland

Our earlier investigations have shown that the full value of fertilizers on grass land is obtained only when the grass is properly used. Seeding, manuring and management are closely connected; we shall therefore describe all the grassland work in this section.

The older Rothamsted experiments dealt only with the manuring of grass for hay; in 1921, however, experiments were begun on the phosphatic manuring of grazing land in Great Field, the results being expressed as live weight increase of the sheep in accordance with the method of the late Sir William Somerville. These experiments* showed that the method, while giving striking results on poor land such as that of Cockle Park, was quite unsuited to land in better condition. It is liable to serious errors arising from differences in the sheep themselves and differences in rate of stocking, and in our

* Report 1923-4, p. 21; Report 1925-6, p. 25; Report 1927-8, p. 33.

experience it can work only on poor land capable of considerable improvement: land, for example, which without manure will produce only about 50 lb. live weight increase of the sheep per acre during the season while after manuring it will produce 75 or even 100 lb. per acre. On more normal grass land, producing some 150-200 lb. live weight increase during the season, the method fails; we accordingly gave it up in 1929.

In later experiments we have used instead the method designed by the late T. B. Wood of Cambridge. The grass is cut repeatedly during the growing season and the separate cuttings are weighed and analysed. This reproduces part of the effect of the animal, but not all; it removes the grass but returns no manure. In spite of this weakness, however, the method has been found to give useful results.

The more recent experiments on grass land fall into three groups, dealing respectively with the laying down to grass, the manuring and treatment of the grass, and the utilisation of the grass.

1. *The laying down to grass.* Up to 1925 there was only one grass field on the farm, Great Field, which had been laid down in the 1870's, a small grass field, New Zealand (7½ acres) laid down in 1907 having been broken up during the war, in 1915*. In 1925 we sowed down Little Knott (10½ acres), and in 1928 other fields also, thereby considerably altering the distribution of the land on the farm.

The areas are:

	Before 1925.	1928 to present time.
Arable	225	122½
Grass	27½	130
Roads, buildings and enclosures . .	27½	27½
Total	280	280

In the sowing down various mixtures were used, some with indigenous and some with commercial strains; various previous treatments were also given. By reason of our heavy head of stock —220 breeding ewes (half-bred, Cheviot ewe by Border Leicester ram), producing 340 lambs; some 60 head of cattle (mostly young), and some 25 breeding sows (mostly Wessex Saddleback)—it is possible to graze the land thoroughly, and the management has been consistently good. At first the herbage on each of the different areas had its characteristic appearance, but under similar treatment these differences began to lessen, and now, 4 years after sowing, the general type of herbage is much the same on all the grassland whatever the original seeding. On Sawyer's field six widely different mixtures were tested, yet the herbage is now fairly similar on all the plots. Rye grass and wild white clover form about 70 to 80 per cent. of the whole; the rest is chiefly cocksfoot, now 15 to 20 per cent. on all plots, though the original seeding of 5 to 10 lb. per acre had corresponded to a variation from 15 to 40 per cent. of the numbers of seed sown. Timothy forms about 5 per cent. of the herbage. The actual figures vary from spring to autumn and from season to season, but the order is the same. Of the other plants sown little survives beyond some red clover. (Table I.)

* See Report for 1915-17, p. 9.

TABLE I.—Comparison of weights of seed sown with percentage area now occupied by the various groups of plants.

†*Composition of Mixtures Sown* 1928. *lb. per acre.*†

Mixtures.	I.	IV.	V.	VI.	VII.	VIII.
Grasses	24	30.5	40	29	29	27
Clovers	4	5	1	5	7	5
Miscellaneous	2	—	—	2	—	—

Percentage area now occupied by the various groups.

1931—*Spring*.

Mixtures.	I.	IV.	V	VI.	VII.	VIII.
Grasses	55.4	49.4	50.7	51.6	46.1	54.0
Clovers	40.1	45.0	40.9	41.9	48.5	39.6
Weeds	0.1	0.2	0.1	0.2		0.2
Chicory	—	—	—	0.7	—	—
Bare Space ..	4.4	5.4	8.3	5.6	5.4	6.2

1931—*Autumn*.

Mixtures	I.	IV.	V.	VI.	VII.	VIII.
Grasses	35.15	31.6	16.3	40.2	44.5	35.7
Clovers	64.05	67.5	82.3	55.1	54.95	64.0
Weeds	0.1	0.3	0.3	0.05	0.1	—
Chicory	0.2	—	—	4.6	—	—
Bare Space ..	0.5	0.6	1.0	0.05	0.45	0.3

1932—*Spring*.

	I.	IV.	V.	VI.	VII.	VIII.
Grasses	62.6	40.65	37.45	60.2	43.6	48.3
Clovers	35.5	57.05	58.73	37.5	54.6	49.7
Weeds	0.2	—	—	0.05	0.3	—
Chicory	0.1	—	—	0.35	—	—
Bare Space ..	1.6	2.3	3.62	1.9	1.5	2.0

† For percentage numbers of seeds of the different plants see Report for 1929, p. 24.

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in the next. The gain in protein may be considerable, much greater than the gain in dry matter; superphosphate gave the following increases in the first year in grass laid in for hay :

Percentage gain in—

	Dry Matter.	Protein.	Phosphoric Oxide P_2O_5.
Braintree (1930)	42	102	97
Northallerton (1931) ..	47	78	195

These results depend entirely on the solubility of the phosphate. In the first year after application water soluble phosphate is most effective, so that superphosphate comes out best. Citric soluble phosphate comes next, hence high soluble basic slag is second. Mineral phosphate and low soluble basic slag are less effective. The value of mineral phosphate as compared with the others changes a good deal according to soil and season. In the drier conditions of Hertfordshire and the Eastern counties it came a long way behind high soluble slag and was very similar to low soluble slag; in the moister, warmer conditions of Devonshire it acted more like high soluble slag and was much superior to the low soluble slag.

In the second year the high soluble basic slag did better than superphosphate at several of the centres, both on the hay land and on the grass repeatedly mown, though it has not yet caught up with superphosphate. At the Devonshire centre mineral phosphate acted as well as high soluble slag, though it is still behind on the two years' programme, but the low soluble slag showed no sign of improvement.

The experiment is being continued to see what happens in the third and fourth years.

Soluble phosphates (both water soluble and citric soluble) increase the amount of phosphoric oxide (P_2O_5) in the herbage by some 50 or 60 per cent.; sometimes as at Northallerton, by much more; and of course this improves its value for forming bone and building up the animal's frame. The amounts involved are, however, only small, and in none of these experiments has much of the added phosphate been recovered in the herbage; at two of the centres the results have been :

Percentage of added P_2O_5 recovered in repeatedly mown herbage.

	Mineral Phosphate.	Low soluble Slag.	High soluble Slag.	Super
Dartington, 1st year ..	4	1	8	11
,, 2nd ,, ..	12	—1	11	10
,, both years	16	0	19	21
Much Hadham, 1st year	3	4	14	17

Here, again, the difference between low soluble and high soluble slags is well shown.

Low soluble slag has given poor results in practically all of our of nitrogenous manure so far studied, and also for mixtures of cereals with leguminous plants such as are used for fodder mixtures. On the grass land the increased growth is obtained chiefly in spring ; in summer and autumn the increase is less, or it may even vanish.* The effect of reducing the leguminous plants is to cut down the protein content of the whole herbage so that the net gain of nitrogen by the whole crop is only small. Non-leguminous crops usually recover 50 per cent. or more of the nitrogen added in the manure, and the recovery is increased by giving a complete fertiliser ; grass land herbage, on the other hand, shows a much smaller recovery—on the Park grass hay plots our highest figure is 37 per cent., when sulphate of ammonia only was given—and the recovery is decreased by using complete fertilisers, it may then fall as low as 14 per cent.

Recovery of added nitrogen in the hay.
Park grass first 18 years.†

Source of nitrogen.	*Other manures.* None.	Phosphate and Potash.
Sulphate of Ammonia ..	37	20
Nitrate of Soda	35	14

For fodder mixtures the recovery was even less ; in some experiments‡ it was even nil.

As against these, the figures for the recovery of nitrogen by non-leguminous crops grown singly are :

Cereals 40—50
Mangolds 60—70
Potatoes 50—70||

In contradistinction to mixed grass and leguminous herbage the recovery of nitrogen is increased by adding potassic and phosphatic fertilisers. When nitrogenous fertilisers are dear they are not very suitable for grazing land unless special precautions are taken to keep the grass young and leafy by frequent and intense rotational grazing. Otherwise the small amount of nitrogen recovered and the depressing effect on the clover are serious disadvantages.

The increase in amount of early growth brought about by nitrogenous fertilisers has the great advantage that it enables the spring grazing to start earlier than would otherwise be possible, and this may often be a great convenience, especially if supplies of roots, silage or other succulent foods have given out—as not infrequently happens. When nitrogenous fertilisers are as cheap as at present they may advantageously be used for accelerating the early grazing whenever this is needed.

Effects of Phosphatic Manures. Phosphates, unlike the nitrogenous fertilisers, increase the proportion of clover in the herbage, and so add greatly to its protein content. This increase is not confined to the spring months, as happens with nitrogenous fertilisers ; it is maintained throughout the season, and is continued

* Summer manuring has not yet been studied.

† In this period complications due to change in reaction were not serious.

‡ Report for 1930, p. 36 ; the results were confirmed in 1931.

|| For details see Artificial Fertilisers Bull. 28, Ministry of Agriculture, pp. 15-18.

This tendency towards uniformity of herbage comes about for two reasons: species which are unsuited to the conditions soon die; and those which, while well enough suited, cannot stand up against competition, are soon crowded out. In order to obtain further information on this important subject, experiments were started by A. R. Clapham and F. J. Richards, in 1928, and developed later by D. J. Watson. These experiments show that Italian rye grass reduces the growth of perennial rye grass mixed with it, perennial rye grass reduces the growth of cocksfoot, cocksfoot reduces the growth of timothy, and timothy reduces the growth of rough stalked meadow grass; in Clapham's phrase the grasses acted as "aggressors" in this order. The order varied somewhat with season; in another year timothy was more "aggressive" than cocksfoot. Watson has extended the observations by introducing clover (late flowering red) and varying the manurial treatments. He finds that the heaviest yield per unit area is obtained by seeding with rye grass and giving a complete manure; if, however, alternate plants of rye grass are replaced by cocksfoot or by clover, the remaining rye grass plants grow much bigger, though the other plants grow much smaller than if they were alone and the total weight of all the herbage per unit area is reduced. In other words, a plant of rye grass suffers less from the competition of a plant of cocksfoot or clover (Montgomery late flowering red) than it does from the competition of another plant of rye grass. The effect of omitting phosphate from the manuring, however, is to cut down the aggressiveness of the grasses considerably, leaving the clover freer to develop; the omission of potash from the manuring proved a greater handicap to the clover. (Table II.)

TABLE II.—Mean yield of dry matter in grms. per square foot.

Seedings.	*Manurial treatments.*				
	Complete Manure.	No N.	No P.	No K.	No Manure.
Ryegrass	68.8	40.3	46.4	45.1	39.2
Cocksfoot	46.4	46.9	33.4	39.0	23.7
Clover..	38.6	34.1	30.3	25.6	24.6
Ryegrass and Cocksfoot ..	52.7	62.8	45.5	65.1	37.0
Ryegrass and Clover ..	62.2	43.3	31.1	43.6	37.7
Cocksfoot and Clover ..	41.3	36.9	29.8	48.2	30.8

In the experiments just described the plants were allowed to complete their growth; they were neither grazed nor mown. This same order of aggressiveness, however, is indicated by the final state of the herbage in the different fields: rye grass, the most aggressive, dominates the rest; among the grasses cocksfoot comes next; then timothy and the others come a long way after or not at all. In other circumstances other grasses, Yorkshire fog, agrostis, sheeps' fescue, become more "aggressive" and may dominate the herbage.

2. *Manuring of Grass Land.*

The experiments on the manuring of grass land have led to some important results. Nitrogenous manuring has increased the growth of grass but depressed the growth of clover. This holds for all forms

TABLE I (continued)—Percentage Botanical Composition.

1930—*Spring.*

	I.	IV.	V.	VI.	VII.	VIII.
Perennial Rye ..	77.5	57.4	61.7	—	—	} 53.7
Italian Rye ..	—	—	—	49.2	57.5	
Cocksfoot ..	3.3	13.4	17.3	15.5	12.6	18.7
Timothy	4.9	8.8	0.7	4.8	9.4	5.1
Fescue	0.3	—	—	3.2	1.4	2.7
Agrostis	0.2	—	—	—	—	—
Red Clover ..	2.1	6.6	0.2	5.2	6.4	6.6
Wild White Clover	6.6	5.6	2.9	11.2	5.5	5.4
Trefoil	—	—	—	—	0.7	—
Chicory	1.4	—	—	5.3	—	—
Weeds	1.4	3.5	2.2	1.7	1.0	2.7
Bare Space ..	2.4	4.7	15.0	3.9	5.5	5.1

1930—*Autumn.*

	I.	IV.	V.	VI.	VII.	VIII.
Perennial Rye ..	44.6	35.3	43.4	—	—	} 30.1
Italian Rye ..	—	—	—	23.8	25.9	
Cocksfoot ..	8.4	21.1	18.6	19.9	16.2	21.7
Timothy	2.1	4.2	0.5	1.5	7.5	4.7
Fescue	0.2	—	0.1	8.6	—	0.9
Agrostis	1.3	—	—	0.1	0.1	—
Red Clover ..	8.1	12.2	0.7	8.9	7.7	14.1
Wild White Clover	28.6	22.0	29.5	31.1	35.5	22.6
Trefoil	—	—	—	—	—	0.7
Chicory	3.4	—	—	2.6	—	—
Weeds	1.2	0.1	0.4	0.6	0.2	0.3
Bare Space ..	2.1	5.1	6.8	2.9	6.9	4.9

For previous measurements see Report for 1930, p. 44 and for 1929, p. 24.
For particulars of seeding see Report for 1928, p. 101.

The most obvious difference between one mixture and another has been that Italian rye grass has persisted as the dominant grass where it was sown without perennial rye grass; otherwise little difference between cheap mixtures and dearer mixtures persisted by the end of four years. It seems clear that, if the farmer is to recover the extra money spent on costly mixtures he must do it within the first few years, or he may never do it at all.

In the intervening years there were differences in yield and composition of the herbage, and in the density of the plants on the ground. The mixtures were sown on April 25th, 1928; in July, 1929. only about 70 per cent. of the land was covered with vegetation, the remaining 30 per cent. being bare; by the spring of 1930 the bare space was reduced to about 5 per cent. The figures were much the same for all the mixtures. Variations in previous treatment, however, caused considerable differences. West Barn, sown on August 29th, 1928, and therefore very late, and Great Knott (A) (S.E. part), sown on May 29th, 1928, on weedy land and without a cover crop, have both been slower in filling up.

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experiments, especially in the South Eastern Counties. It is said to be more effective in acid soils in Scotland and in the North of England, and if this be so it might be attributed as much to the lime as to the phosphate. Precise comparisons are difficult to make, but the lime value of slag approaches that of an equal amount of ground limestone. There may also be an advantage in supplying lime and phosphate together ; at any rate, on some acid soils phosphates rapidly lose their availability as the result of chemical reactions in the soil.

HOME-GROWN FOOD FOR ANIMALS

Several methods are studied for providing *keep for animals* when grain supplies fall short.

Fodder Mixtures. Mixtures of leguminous and cereal crops are grown (e.g. vetches, barley, beans), cut green, converted into hay or silage, or allowed to ripen for use as straw and crushed grain. These crops are cheap and easy to grow ; they keep down weeds, and they have proved of great value as food stuffs because of this elasticity in use ; no other crops can be consumed in such a variety of ways. The manuring of a mixture, however, differs from that of a single crop because the element of competition comes in. The crops grown without manure, or with potash or phosphate only, are rich in protein and starch equivalent ; they make excellent feeds. Nitrogenous manures, such as sulphate of ammonia and nitrate of soda, increase the growth of the cereal considerably, but reduce the vetches and peas ; the total weight of crop per acre is greater, but the feeding value is entirely changed. The new crop contains no more protein, but more starch equivalent per acre ; it resembles hay of moderate quality.

Several different mixtures are being sown at different times of the year to see how far it is possible to arrange for a sequence of these crops suitable for the needs of a flock master, a dairy farmer, or a crop-drying apparatus.

Lucerne. The work on inoculation of lucerne is continuing, and search is being made for new strains of organisms more efficient than the one at present being distributed to farmers. These experiments have revealed great differences in effectiveness between different strains occurring in different soils ; none, so far, is as good as the one we use. But the smallness of the number so far studied gives us grounds for hoping that our search may be rewarded by the discovery of one that is far better.

Nitrogenous manuring proved ineffective in pot experiments to raise the yield of lucerne grown by itself, and it lowered the yield of lucerne grown with grass, besides depressing the formation of nodules, apparently by reducing the root development. The protein content of the mixed herbage was decreased by the nitrogenous manure.

Sales of cultures to farmers have again exceeded all records, amounting to over 9,000 during the season, enough to inoculate over 4,500 acres.

POTATOES

The year 1931 concludes the series of large replicated experiments with potatoes using a 9-block design, which has been found to give particularly precise comparisons. The experiment has been tried four times at Rothamsted, in 1927, 1929, 1930 and 1931, and once at Woburn, in 1929.

The comparisons to be made consisted of all combinations of 0, 1 and 2 unit applications of ammonium sulphate, 0, 1 and 2 units of potash, applied as sulphate, chloride, or potash salt containing potassium chloride. Thus, without replication, 27 different plots would have been required, of which 21 would have been treated differently. The design adopted was to assign 81 plots to the experiment arranged in 9 blocks of 9 plots each, such that within each block, 3 plots without potash received respectively 0, 1, 2 units of nitrogen, and likewise the three plots with single potash, and the 3 with double potash. The 3 plots with single or double potash within each block again were assigned to the 3 types of potash manure. The blocks thus differed only in the association of the 3 kinds of potash with the 3 quantities of nitrogen, and in different blocks each kind of potash occurs 3 times with each quantity of nitrogen.

The effect of this arrangement is to give to the comparisons of primary interest the full precision of replication within small blocks, while sacrificing information on possible hypothetical but highly complex interactions between the different manures. In all experiments save the first, each plot also was divided into two halves, ascribed independently at random to receive or not to receive a dressing of superphosphate.

The response to nitrogen in the five experiments is shown in Table III.

TABLE III.—Average response to Nitrogen as Sulphate of Ammonia.

Yields in tons per acre.

	Sulphate of Ammonia applied			Size of Single Dressing	Average increased yield of potatoes. Tons per cwt. of N. per acre.		
	None	Single Dressing	Double Dressing	Cwt. Nitrogen per acre	Single Dressing	Additional Dressing	Both Dressings
Rothamsted—							
1927 ..	6.42	7.27	7.32	.42	2.02	0.12	1.07
1929 ..	4.78	5.48	5.85	.30	2.33	1.23	1.78
1930 ..	8.04	9.22	9.65	.20	5.90	2.15	4.02
1931 ..	10.70	11.62	12.37	.20	4.60	3.75	4.18
Woburn—							
1929 ..	4.85	5.11	5.17	.30	0.87	0.20	0.53

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Average response to Potash

Yields in tons per acre.

	Yield in tons per acre. Potash applied.			Size of Single dressing. cwt. .K_2O per acre	Average increase or decrease in yield of Potatoes. Tons per cwt. K_2O per acre.		
	None.	Single Dressing	Double Dressing		Single dressing	Addition-al dress-ing	Both dressings
Rothamsted—							
1927 ..	6.92	7.13	6.95	1.0	0.21	—0.18	0.02
1929 ..	5.21	5.45	5.45	0.50	0.48	0.00	0.24
1930 ..	8.40	9.04	9.48	0.40	1.60	1.10	1.35
1931 ..	11.60	11.40	11.70	0.40	—0 50	0.75	0.12
Woburn—							
1929 ..	4.83	5.04	5 25	0.50	0.42	0.42	0.42

The returns in tons per cwt. of nitrogen are all significant. The variation between the different years at Rothamsted is evidently ascribable to two main causes : (1) The unit quantity of nitrogenous application has been varied, and as is only to be expected, the highest returns per cwt. are found when the unit employed is smallest; (2) There is great variation in the yield from year to year, and the highest return is to be expected, as is indeed found to be the case, in the years of highest yield. These appear to be the major factors in determining the return per cwt. of nitrogen.

A second respect in which the plots treated with more nitrogen differed from those treated with less, lies in the response to superphosphate. The average difference in yield between the sub-plots receiving superphosphate and the twin sub-plots receiving none is given in Table IV.

TABLE IV.—Increased yield of potatoes: tons per acre given by superphosphate with varying supplies of sulphate of ammonia.

	No Sulphate of Ammonia.	Single Dressing.	Double Dressing.	Cwt. P_2O_5 per acre supplied.
1929	0.23	0.51	0.78	.4
1930	0.62	0.49	1.30	.5
1931	—0.08	0.44	0.63	.5
Average : Rothamsted ..	0.26	0.48	0.90	—
Woburn 1929	0.36	—0.14	—0.29	.4

At Rothamsted it is seen that there is a very general and pronounced tendency for the plots receiving more nitrogen to respond better to superphosphate than the plots receiving less, or, what amounts to the same thing, for the plots receiving superphosphate to respond better to nitrogenous manures than the plots receiving none. At Woburn, in the one year tested, there is a marked and statistically significant reversal of this effect. The yields in this experiment were very small, but this does not impugn the significance of the result, which it is hoped to examine more fully by later experiments.

The interaction of response to nitrogenous and phosphatic manures is the only interaction to show itself significantly in this series of experiments; this supplies an *a posteriori* justification for sacrificing information in a group of the remote interactions, for the sake of added precision in the main effects. The actual data, moreover, for each year, show that the interactions sacrificed are in fact unimportant, while the comparisons which have been made more precise are of direct interest.

An effect on which higher precision than that actually attained would be most desirable concerns the contrast between sulphate, muriate and potash salt as sources of potash.

Table V gives the average yields in the five experiments, together with the two comparisons muriate *v.* potash salt, and sulphate *v.* the average of the other two. Only in 1927, when the precision of the experiment was considerably higher than has since been attained, could the results for a single year be judged significant.

TABLE V.

Comparison of Sulphate of Potash (S) with Muriate of Potash (M) and Potash Salt (P) as Fertilisers for Potatoes. Yields of Potatoes, tons per acre.

	S	M	P	M–P	S–½ (M+P)
1927	7.36	7.08	6.59	+.49	+.52
1929	5.47	5.45	5.44	+.01	+.03
1930	9.47	9.42	9.10	+.32	+.16
1931	11.80	11.31	11.68	—.37	+.21
Woburn, 1929..	5.28	5.05	5.20	—.15	+.30
Mean	7.88	7.66	7.60	+.06	+.25

Nevertheless, in all five comparisons sulphate has shown a positive advantage over the two forms of chloride, in such a way as to confirm unmistakably the 1927 result. The average gain is only about ¼ ton to the acre, or 2 to 3 per cent. of a fair yield. As between the muriate and the potash salt, however, the five experiments show no significant or consistent advantage.

FERTILISERS AND MATURATION OF BARLEY

Studies by W. E. Brenchley in the Botanical Department have shown that the different fertilisers influence the maturation of barley in different ways.

Phosphatic fertilisers hasten the maturation both of the straw and of the grain. On the other hand, nitrogenous fertiliser and sulphate, whether of potassium, calcium or ammonium, hasten maturity of straw but not of grain.

Mustard is also slightly hastened in maturation by sulphate, but not on all soils; the effect was not shown, for example, on a fen soil from Cambridgeshire.

RELATIVE IMPORTANCE OF NUTRIENTS AT DIFFERENT STAGES OF PLANT GROWTH

In water culture experiments barley deprived of nitrogen during early growth, but receiving it later, was soft and sappy, tillered little and formed little grain, showing that the addition of nitrogen at a later stage did not enable it to make up for the early deficiency, as compared with plants that had had nitrogen from the start. In some instances late additions of extra nitrogen reduced grain formation by promoting fresh tiller formation. Spratt Archer suffered more than the earlier ripening Goldthorpe, which continued filling its grain in spite of the lateness of the nitrogen application.

SUGAR BEET

Sugar beet is included in the new rotation experiments at Rothamsted and Woburn which measure each year the effects of sulphate of ammonia, superphosphate and muriate of potash on crops grown without dung in a six course rotation. In 1931 sulphate of ammonia gave large and significant increases in yield at both Rothamsted and Woburn and muriate of potash a large and significant increase at Woburn; superphosphate gave small non-significant increases at both centres. (Table VI.)

TABLE VI.

Average increased yield in cwt. of sugar beet per acre given by :—

		Sulphate of Ammonia. 1 cwt. per acre.	Muriate of Potash. 1 cwt. per acre.	Superphosphate 1 cwt. per acre.
Rothamsted	Roots ..	12*	4†	2†
	Tops	16†	0†	—11†
Woburn	Roots ..	11*	19*	4†
	Tops	15†	47*	5†

* Significant. † Non-Significant.

In view of the poor responses to fertilisers sometimes obtained at Rothamsted where the soil is too heavy and sticky to be favourable to sugar beet, different methods of cultivating the crop were tried. Loosening the subsoil had a negligible effect, delay in ploughing under the dung reduced the yield, whilst reducing the distance between the rows increased the yield. The last point has special interest since precautions were taken to have the same number of plants per acre in both comparisons. Other experiments have shown that the yield may be increased by putting the rows closer together but it was not clear whether the advantage was from the closeness of the plants or, what is more likely, from the increase in the total number of plants per acre. In the 1931 Rothamsted experiment the rows were in one case 24 inches apart with plants 10$\frac{2}{3}$ inches apart within the rows and in the other the rows were 16 inches apart and the plants also 16 inches apart with the rows, thus giving equal numbers of plants per unit area. The fact that there was a significant advantage of the square over the oblong spacing shows that the yield of beet depends not only on the numbers of plants but also on their arrangement in the field.

	Yield of roots. tons per acre	Yield of tops. tons per acre
Square spacing (16 ins. rows by 16 ins.) ..	13.2	16.2
Oblong spacing (24 ins. rows by 10⅔ins.) ..	12.1	15.6
Dung ploughed in at once	13.0	16.8
Dung left on land 3 weeks before ploughing under	12.3	15.1
Ploughed only	12.8	16.0
Ploughed and subsoil loosened	12.5	15.9

At Woburn where the soil is lighter and cultivation for sugar beet is easier, experiments were made (1) to compare sulphate of ammonia and nitrate of soda applied at different times, (2) to test the effect of salt, (3) with different methods of incorporating the fertilisers into the soil. On the Continent it is common practice to give nitrogenous fertilisers well in advance of sowing the sugar beet and in some cases even in the autumn. At Woburn in the wet spring and summer of 1931 the application of sulphate of ammonia and nitrate of soda three weeks before sowing gave on the average 1.51 tons per acre less sugar beet roots and 1·58 tons per acre less tops than application at the time of sowing. The reduction of yield was doubtless due to the washing out of nitrate by heavy rainfall on a light soil. Sulphate of ammonia gave more roots and a better sugar content than nitrate of soda, and, contrary to the results of earlier years, common salt had no effect. There was no advantage from thoroughly incorporating the fertilisers into the soil by means of a rotary cultivator as compared with harrowing. A number of experiments over several years at Woburn and elsewhere have shown no very marked differences in comparing nitrate of soda given in the seed bed with that top dressed but on the whole the evidence favours the seed bed application.

Fertiliser experiments on two fenland soils produced only small and uncertain effects. The experiments on mineral soils at other centres were in general harmony with conclusions drawn in earlier years, which may be summarised as follows. For equal amounts of nitrogen there is little difference between the alternative forms of fertiliser except that nitrate of soda tends to produce more top, and to depress the sugar content more than sulphate of ammonia, whilst calcium cyanamide sometimes gives rather inferior results. Potash salt is generally superior to muriate of potash, doubtless on account of the common salt it contains. If low grade potash manures are not used, it is generally advisable to give common salt. On good quality clay and silt loams farmyard manure supplies most of the nutrients needed and only a light dressing of a complete fertiliser mixture is required. On light soils good returns are obtained from complete fertiliser mixtures even when used in conjunction with dung. A suitable mixture would be 2-3 cwt. sulphate of ammonia, 2-3 cwt. potash salt (20 per cent.) and 3-4 cwt. superphosphate per acre.

EXPERIMENTS AT OUTSIDE CENTRES

Many experiments are made under the direction of H. V. Garner at outside centres where the crop in question is well understood and where therefore proper cultivation and management is assured. These experiments are of great value in showing how far the Rothamsted results are generally applicable and what modifications are caused by differences in soil, climate, or general husbandry conditions. Full accounts are given in H. V. Garner's articles in the Journal of the Ministry of Agriculture.

Broadly speaking the Rothamsted results usually represent pretty well the average results from the outside centres.

POTATOES. *Phosphatic manuring.* The effect of superphosphate on potatoes has been tested at nine of the outside centres. On the fen soils marked increases were obtained not only from a dressing of 5 cwt. superphosphate, but even from the additional 5 cwt. making 10 cwt. in all. A similar big increase was obtained on the oolite limestone at Burford: 4 cwt. super added 1½ tons per acre to the yield which without phosphate had reached only the low figure of 4.1 tons per acre. On the other hand a rich silt at Wisbech, which has been in the past heavily manured with super, responded only to the first dose of 2 cwt. super and not at all to additional dressings. Two centres showed no response: Owmby and Biggleswade: Owmby has in all the tests shown a response only once. At Rothamsted the response was this season only slight: 2 cwt. potatoes per cwt. super.

Early potatoes on an acid sand at Potton did not respond to superphosphate. The yields are given in Table VII.

TABLE VII. Effect of superphosphate on potatoes at different outside centres

Centre	Soil	Yield tons per acre No Phosphate	Cwt. per acre increase over No Phosphate			Size of dose of Superphosphate. Cwt.
			1st dose	2nd dose	3rd dose*	
Main Crop.						
March	Peaty Fen.	6.46	18	28	—	5
Ely	Rich Clay Fen	7.72	29	55	—	5
Wisbech (G. Major, Esq.)	Rich Silt	11.18	8	Nil	Nil	2½
Wisbech (Messrs. Hickman & Co.)	Rich Silt	12.30	17	16	15	2
Burford	Limestone	4.13	32	30	23	2
Owmby Cliff	Limestone	7.01	—4	—1	—8	2
Biggleswade	Sandy Gravel	10.70	Nil	—	—	2½
Tunstall	Sand	9.85	32	—	—	4
Earlies.						
Potton	Sand	4.05	—4	5	—4	2

* The third dose is double the second dose.

This year potassic fertilisers had but little effect either at the outside centres or at Rothamsted. March had been sunny but from April onwards till October the months had been much wetter, more

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sunless and colder than usual : in general character the season was not unlike those of 1913 and 1926, yet 1926 had been a good potash year. Information is steadily being accumulated about the relation between character of the season and fertiliser efficiency, but the subject is full of difficulties.

Nitrogenous fertilisers on the other hand were distinctly effective, the increase per cwt. sulphate of ammonia being in cwt. potatoes :

	1st dose.	2nd dose.
Rothamsted........................	18	15
Biggleswade.......................	14	10
Midland Agricultural College	14	20
Ely	16	—
March	6	—

These last two were black fen soils on which responses would not usually be expected, though in our earlier experiments on black soils we have obtained quite good responses : they have been, for 2 cwt. Sulphate of Ammonia :

	Cwt. potatoes. additional crop.
1928 Stourbridge	38
1929 Bourne	20

In comparisons with Nitrate of Soda and Cyanamide, Sulphate of Ammonia gave on the whole the best results for main crop potatoes. Nitrate of Soda came next and Cyanamide third.

For early potatoes, on the other hand nitrogenous fertilisers were practically ineffective : only Nitrate of Soda showed any sign of acting : this is the first set of experiments we have made with this crop and we intend to continue them.

Winter cabbages grown immediately after lifting the potatoes however, benefited by the nitrogen.

Organic Manures. On potatoes organic manures have again proved less effective than the standard artificials. The experiment was made this time by the staff of the Midland Agricultural College : fish manure was tested against home mixed artificials and the I.C.I. compounds ; fish manure gave the smallest and I.C.I. compound the largest increase.

BRUSSELS SPROUTS. On Brussels sprouts at the Swanley Horticultural College, however, both poultry manure and high-grade guano proved better than artificials : the results were :

Brussels Sprouts, Cwt. per acre.

	No Nitrogen	Poultry Manure	High Grade Guano	Artificials Full N	Artificials Half N
Sprouts	48.05	53.96	51.79	47.16	45.60
Blown Sprouts ..	14.12	20.59	19.70	18.64	17.08
Total	62.17	74.55	71.49	65.80	62.68

KALE. This important crop has not received much attention from agricultural investigators : we have started several experiments with it which will be developed as the results begin to emerge.

It has great power of utilising added nitrogen. An experiment made at the Midland Agricultural College with marrowstem kale gave marked responses even to 4 cwt. Nitrate of Soda.

	Nitrate of Soda, Cwt. 0	1	2	4	*Standard Error.*
Kale, tons ..	15.31	18.20	19.06	22.42	0.677

HAY. *Nitrogenous manures.* The average increased production of hay this year has been 6 cwt. for 1 cwt. Sulphate of Ammonia.

SOIL FERTILITY AND MECHANISATION.

The systematic use of large scale machinery on the farm, called for convenience "mechanisation," is usually combined with a reduction in the number of live stock kept, and hence causes certain modifications in the fertility relationships of the soil. Four important groups of problems are being investigated.

(1) Can fertility be sufficiently maintained by artificial fertilisers alone or is it necessary to return the straw to the land in the form of manure? If the straw must be returned, what is the best way of doing it?

(2) Is it possible to produce, by any cultural process, the same good effects on light land as are obtained by sheep folding?

(3) Green manuring.

(4) Fallowing.

The classical experiments at Rothamsted have shown that soil fertility can be kept at a certain moderate level by the use of artificial fertilisers alone without the use of farmyard manure. In general, however, the growth of the crop has not been enough to keep down weeds, and much expense has been entailed in cleaning. A combination of artificial fertilisers with occasional fallows, however, has proved effective in maintaining yields at low expenditure in labour but with a loss of one year in four or five.

The return of the straw to the land can be effected in several ways; three are under investigation:

(1) It may be converted into farmyard manure in the usual way. In our experiments, about 25 per cent. of the nitrogen in farmyard manure is recovered by the plant as against about 50 per cent from artificial fertilisers.

(2) It may be decomposed by the method developed in these laboratories by H. B. Hutchinson and E. H. Richards and put on a commercial basis by the Adco Syndicate; the straw is treated with the necessary nitrogen compound, phosphate and limestone, to encourage the activity of micro-organisms effecting the decomposition.

(3) It may be ploughed under, and the necessary nitrogen and phosphate given in the form of artificial fertilisers. In the autumn a smaller addition is necessary than in the spring, because the soil already contains some nitrate, which if it were not used by the organisms would probably be washed away in the winter.

If this method proves feasible in practice it has the advantage of economy in labour, for the corn could simply be stripped and the straw ploughed under while the soil was still warm.

These problems are being studied in the four-course rotation experiment (p. 129).

Green Manuring.

This affords a simple method of manuring both heavy and light soils and it requires no live stock ; it can be practised on completely mechanised farms. Its advantage in certain conditions has long been recognised, but of late years a number of instances have been recorded where it proved ineffective. The most striking is at Woburn, where, over a series of years, green manuring with tares and with mustard has failed to increase the yield of wheat or of barley. Experiments carried out a few years ago on several other farms with the help of a grant from the Royal Agricultural Society of England also yielded negative results.

There are, however, undoubted successes, and investigations have been made and still are in progress to find the conditions under which green manuring is likely to give useful results. Two of the most important factors are the composition of the plant at the time of ploughing in and the time at which the ploughing is done. If the ratio of carbon to nitrogen in the crop is more than 20, the organisms effecting the decomposition may require more nitrogen then is supplied by the crop, in which case they draw on the soil nitrates that would otherwise either be washed out or taken by the plant. If, however, the ratio is less than 20, the organisms may not need the whole of the nitrogen, they then leave the excess in the soil in the form of nitrate, which as before, is either washed out or taken by the plant. Investigations have shown that at Woburn the tares crop failed to increase the growth of wheat because it was ploughed under in autumn, and rapidly gave rise to nitrate, which was washed out because the wheat plant, being insufficiently developed, could not assimilate it, and in the following spring the wheat suffered from nitrogen starvation. The mustard during its active growth assimilated nitrate and so saved it from loss, but some nitrate escaped assimilation and was washed out because the crop was too small or the soil was bare. Also after the mustard was ploughed in, some of it probably decomposed too slowly to supply useful quantities of nitrogen to the wheat. The value of nitrogen depends on the time when it is given ; when given late to barley it reduced the ear tillers and the number of fertile grains and increased the vegetative tillers. It seems clear that the process of green manuring needs to be clearly adapted to the soil and the crop so as to ensure liberation of nitrate only when the plant is in a position to take it up.

Fallowing.

Since the Broadbalk field was divided into five sections in 1925 to permit of rotational fallowing* it has been possible to accumulate considerable information about the effects produced.

The effect on the weed population is being studied by W. E. Brenchley and K. Warington.

The census of buried weed seeds on Broadbalk field which they began in 1925 is still being continued by the examination of samples taken yearly, in order to determine the rate at which recolonisation occurs after fallowing. The rapidity with which some of the worst seeds reassert themselves is alarmingly great, and indicates the

* See 1930 Report, p. 27, for particulars

necessity for diligent cultivation immediately the land returns under crop. After a single year under crop the soil may be re-stocked with as many weed seeds of some species (as thyme-leaved sandwort) as were present before fallowing, or even more. After three years in crop the numbers may far exceed the original stock ; black bent and chickweed are notable instances. (Table VIII).

TABLE VIII.

Broadbalk Wheat Plots.

Effect of 2 years' fallowing.

		Buried Weed Seeds Millions per acre*.			
		Before Fallowing (1925)	After 2 years Fallow. (1927)	After 1 year in Crop. (1928)	After 3 years in Crop.† (1930)
Alchemilla arvensis	Lady's Mantle	11.4	3.7	10.0	16.5
Alopecurus agrestis	Black Bent	11.3	0.5	4.8	36.5
Arenaria serpyllifolia	Thyme-leaved Sandwort	0.8	0.75	4.5	3.3
Myosotis arvensis	Forget-me-not	2.1	0.4	0.7	1.4
Papaver spp.	Poppy	82.6	38.0	34.9	34.4
Stellaria media	Chickweed	0.2	0.03	0.5	1.8
Veronica arvensis	Field Speedwell	6.8	1.5	7.3	22.8
,, *hederaefolia*	Ivy-leaved Speedwell	2.0	0.8	1.1	2.4
,, *buxbaumii*	Large Field Speedwell	0.2	0.2	2.0	0.3

Effect of 4 years' fallowing.

		Buried Weed Seeds, Millions per acre*.		
		Before Fallowing (1925)	After† 4 years Fallow. (1929)	After† 1 year in Crop (1930)
Alchemilla arvensis	Lady's Mantle	12.3	1.6	5.3
Alopecurus agrestis	Black Bent	11.3	0.2	3.7
Arenaria serpyllifolia	Thyme-leaved Sandwort	0.9	0.7	0.9
Myosotis arvensis	Forget-me-not	0.6	0.04	0.1
Papaver spp.	Poppy	112.0	23.3	26.9
Stellaria media	Chickweed	0.3	0.4	1.4
Veronica arvensis	Field Speedwell	6.5	0.6	1.6
,, *hederaefolia*	Ivy-leaved Speedwell	1.7	0.2	0.4
,, *buxbaumii*	Large Field Speedwell	0.3	0.3	0.3

Soil improvement due to fallowing is as advantageous to the weeds as to the crop, and those weed seeds which survive the fallow are able to produce very strong plants which form large supplies of seed to restock the soil. If the number of weeds could be kept down for a year or two after fallow, till the soil conditions became more normal, the growth might perhaps be less and the rate of seeding less prolific. Even after a bare fallow lasting for four years, the increase in the buried seeds of some species, such as black bent (*Alopecurus*

* Each figure gives the mean of 28 determinations, the aggregate area examined being 7 square feet. One million per acre corresponds with 160 per 7 square feet.

† Figures incomplete. Will be higher.

agrestis) and lady's mantle (*Alchemilla arvensis*) is very rapid, but others appear to be more easily controlled by cultivation methods.

One point of great practical importance is that fallowing operations may be worse than useless if they are not thorough. After the autumn ploughing the practice is to have the ground untouched till early spring, but during this period a few weeds, as shepherd's purse (*Capsella bursa-pastoria*), thyme-leaved sandwort and large flowered speedwell are able, in favourable seasons, to flower and seed so that there may be more seed present in the soil after fallowing than before. To make fallowing effective, cultivation needs to be frequent, and to be carried out during the winter months as well as during the normal growing season.

TABLE IX.

Ineffectiveness of fallowing, as a means of destroying certain weeds.

Arenaria serpyllifolia.	Millions per acre.
Before fallowing	0.9
After 1 year's fallow	1.0
,, 2 ,, ,,	0.7
,, 3 ,, ,,	1.0
,, 4 ,, ,,	0.7 *

ELEMENTS NEEDED BY PLANTS ONLY IN SMALL QUANTITIES

Plants are made up of some nine or ten elements in rather large amounts ; of these carbon, hydrogen and oxygen come from the air and water, and are not usually under control in this country ; nitrogen, potassium, calcium and phosphorus come from the soil and are regularly controlled by the use of artificial fertilisers ; magnesium, sulphur and iron occur in some of the fertilisers, and are therefore supplied incidentally ; in any case they are usually present in sufficient amount in the soil.

Besides these, however, there are other elements needed only in very small amounts. How many of these there may be is not yet known. The most detailed studies have been with boron, the necessity for which has been demonstrated by K. Warington in these laboratories.

Plants without boron neither grow nor flower normally—special symptoms are produced, including death of the apices and breakdown of conducting tissues. These effects appear much more rapidly in summer than in spring or autumn. The difference is not in the temperature but in the hours of daylight, since plants grown without boron in summer but allowed only 9 hours of daylight are also slow to develop the symptoms, and behave, indeed, like plants grown in spring.

There is some superficial resemblance between the effects of light and of boron. Plants supplied with boron but allowed only a short period of light every day fail to develop flowers just as if they were deprived of boron ; but they will produce flowers when they are given more light, while those without boron will not.

The amount of boron needed by plants is exceedingly small.

* Figures incomplete. Will be higher.

Of all plants yet tested, broad beans seem to require most, but even for them access to 0.2 mgms. and probably less, of boric acid (H_3BO_3) per week per plant during the growing season suffices, while peas and barley require much less. Apparently all plants require some.

These very small amounts are usually, if not invariably present in the soil. No clear case is known where addition of boron has improved plant growth in the field. There are a few possible exceptions which deserve further investigation : *e.g.* a certain tobacco disease in Java may be attributable to boron deficiency.

When the need of the plant is satisfied, further quantities of boron may easily do much harm ; citrus growers in California have suffered loss through the presence of boron in the irrigation water. Manuring with boric acid is certainly not recommended ; indeed, it is strongly to be deprecated.

SOIL PHYSICS

During R. K. Schofield's charge, the work on soil cultivation was continued.

In the laboratory further search was made for easy and rapid methods of soil testing. A new machine, called the Pachimeter, was devised by R. K. Schofield and G. W. Scott Blair to study the process of rolling a plastic cylindrical mass of moist soil or clay between two plates under a gradually increasing load. It was found that the load at which permanent lengthening of the cylinder first occurs is, within limits, a definite and reproducible value which varies considerably with the nature of the soil or clay examined, and this measurement promises to be of value in soil classification and surveying. The method has attracted a good deal of attention outside the sphere of soil investigations, and especially in the flour-milling industry.

R. K. Schofield has developed a new rapid method for determining the " base exchange capacity " of a soil : it consists in measuring the decrease in conductivity of a potassium phosphate solution when a weighed quantity of soil is introduced.

C. G. Hawes, Executive Engineer, Lloyd Barrage and Canals Construction, Sind, spent nine months in the department studying methods of distinguishing soils likely to give trouble under irrigation conditions.

METHODS FOR AGRICULTURAL SOIL SURVEY

In recent years there has been marked development in the number and extent of the soil surveys undertaken in this country and elsewhere, and it has become essential to work out satisfactory methods for field and laboratory examinations. Much progress has already been made in the United States and in Russia. The Russian methods have been studied in Russia during the past few years by several members of the Rothamsted staff. E. W. Russell worked for some months with a soil survey party in South Russia ; G. V. Jacks and H. L. Richardson have worked there for shorter periods ; while E. M. Crowther, H. L. Richardson, and the Director have traversed the country with the leading Russian soil experts to learn their methods from them at first hand.

Somewhat different methods are used in the United States. In order to make a careful study of these, one of their leading soil surveyors, L. L. Lee of the New Jersey Experimental Station, was invited to visited Rothamsted for a year during which time he made two typical surveys: a detailed survey of the Rothamsted farm, showing how the methods are used in making an intensive survey of a small area, and a more general survey of Kent, showing how they deal with a large area in a limited space of time. A number of meetings took place with soil surveyors in this country, out of which emerged agreements as to procedure which will prove of great value for future work. One of the German "Kulturtechniker" Dr. Janert, was also invited here for a year to apply his heat of wetting and other methods to the study of British soils.

GENERAL MICROBIOLOGY

Much of the earlier work of the Station was concerned with the effects of partial sterilisation of soil, and the view was expressed that the increased numbers of bacteria following on the partial sterilisation treatment resulted from the suppression of soil protozoa. This has been confirmed by much subsequent work and regular relationships have been traced between the numbers of bacteria and those of protozoa; when one is high the other is low, and *vice versa*.

The further deduction was made that these higher numbers of bacteria produced a larger amount of ammonia in the soil and therefore increased the total amount of plant food. It now appears that this requires important qualification; the amount of ammonia and carbon dioxide produced does not increase proportionately to the numbers of bacteria, but much less. As the bacterial numbers increase so their individual efficiency decreases. In experiments with cultures of bacteria in artificial media it was shown that additions of the protozoa *Colpidia* reduced the bacterial numbers, and increased the individual efficiency. The relationships between numbers and efficiency could be expressed by a straight line, but the actual line for the protozoa-free cultures differed from that expressing the results for the cultures containing protozoa in a way suggesting that *Colpidium* stimulated ammonia production by the bacteria quite apart from its effect in reducing numbers of bacteria.

This work on the interaction of the various groups of the soil organisms is being continued.

The work on nitrification described in the last Report is being continued.

EFFLUENT FROM SUGAR BEET FACTORIES

The study of the purification of effluents from sugar beet factories has been continued, and useful information has been obtained in regard to the possibility of inoculating filters with particular strains of bacteria.

SOIL BACTERIA

Bacterial Numbers in Field Soils

An essential part of the work of the Bacteriological Department is to form estimates of the numbers of bacteria in the soil. The plating method was used at Rothamsted for many years, and it served the useful purpose of showing which factors increased and which decreased the numbers of bacteria in the soil, though it failed to record many of the groups, so that the results were always low.

A great improvement in the method of counting was made in 1928 by H. G. Thornton and P. H. H. Gray ; direct counts are made from stained films, and the difficult problem of estimating the minute amount of soil involved is overcome by mixing with a weighed quantity of the soil a known volume of a suspension of indigo particles the thickness of which has been determined with a haemocytometer. Bacteria and indigo particles are both counted in the stained films from this mixture, and, from the ratio of bacteria to indigo particles, a simple calculation gives the numbers of bacteria per gram of soil.

The method is not only much more rapid than the older one, but much more complete. The plating method usually gives numbers of the order 10 to 30 millions per gram of soil from our plots ; the new method gives numbers varying from about 1,500 million to 4,000 million per gram of soil. On the Hoosfield barley plots, for example, the numbers varied from 1800 millions per gram in the soil of Plot 1—0 (unmanured since 1856) to 3,600 millions on Plot 4AA (complete artificial fertilisers, including nitrate of soda every year since 1856). Further, the numbers in the different plots varied in much the same way as the yields, so that bacterial counts give some indication of the order of productiveness.

Bacteriological Methods of Assessing Soil Fertility

In recent years several bacteriological methods have been devised for assessing either the general fertility of the soil or else some special deficiency such as lack of lime or of phosphate. One of the simplest and most elegant is that of Winogradsky and J. Ziemiecka, and fortunately we were able to arrange with the authorities of the Pulawy Agricultural Institute, Poland, for Mme. Ziemiecka to work for some months in our laboratories applying the " plaques moulées " method to the soils of the classical plots. The results gave correct indications as to the presence or absence of adequate phosphate and lime supplies on the plots receiving no nitrogenous manure or only the normal dressings, but not on plots to which heavy dressings of nitrogenous manure were given. Further examination showed, however, that Azotobacter was either absent from these soils, or occurred in only small quantities ; when a culture of it was added as part of the test the results came out entirely correctly.

Counts of nitrifying organisms were made from some of the plots, and these showed some relationship with soil fertility.

During the course of her experiments Madame Ziemiecka isolated an organism of considerable interest, whose cells possessed the power of absorbing certain indicators such as Brom Thymol Blue. She also obtained a *Myxobacterium* which attacks cellulose, the first found in our soils.

THE NUMBERS OF FUNGI IN THE ROTHAMSTED SOILS

The quantitative methods worked out in the Mycological Department have been used by Jagjiwan Singh for estimating the numbers of fungi and actinomycetes in the Rothamsted soil. The types of fungi were much the same in the differently manured plots, but the numbers both of types and of individuals were always higher on the more fertile plots. There was no evidence of seasonal fluctuations in numbers, such as have been recorded for bacteria and for protozoa. Barnfield (continuous mangolds, the leaves always ploughed in) contained more fungi but less actinomycetes than Broadbalk (continuous wheat); there was also some difference in the proportions of the fungal population. Barnfield contained more *Penicillia* and *Dematia* but less *Fusaria* and *Verticillia* than Broadbalk.

VIRUS DISEASES OF PLANTS

This work is carried out by J. Henderson Smith, with the assistance of J. Caldwell, M. A. Hamilton and F. M. L. Sheffield. It falls into three sections:

1. *The Nature of Virus.* Juices extracted from diseased plants are usually themselves infective and remain so after passage through most porcelain filters. By using graded collodion membranes it has been found possible to determine a limiting porosity (varying with different viruses), above which the filtrate remains infective but below which the virus is held back and the filtrate does not cause disease. Again, when infective material is rubbed on the leaves of certain plants, virus enters through the broken hairs and produces a local lesion at the point of entry. If the material is suitably diluted before rubbing on the leaves, infection occurs in only a few of the many broken hairs and only a few local lesions result. Such experiments show that in infective material virus exists in a particulate state and not generally diffused. The size of these particles has been estimated approximately; but it is still uncertain whether the virus is itself particulate or merely attached to other particles. Work is in progress to determine which is the true explanation. Nothing has yet been found incompatible with the view that virus is a living organism.

It is frequently asserted that viruses are invisible stages in the life-cycle of visible bacteria, largely because there is a regular association of specific bacteria with certain virus diseases. We have investigated one such case, and find that when the plants are grown aseptically throughout from sterile seed, inoculation with bacterium-free virus produces the typical disease, and the bacteria usually associated with it do not appear. It is also said that intracellular inclusions which are characteristic of virus disease are either colonies of the virus or visible stages of a usually invisible parasite. The development of such inclusions has been watched in individual living cells from their first beginnings to their complete formation, and in the cases investigated they are essentially aggregates, made up by the coalescence of small particles of cytoplasm which has been locally coagulated or precipitated under the influence of the virus.

A cinematograph film has been prepared showing the whole process. The final form of the inclusion varies with the host plant and with the virus.

2. *The behaviour of Virus in, and its effects on, the host plant.* Within the infected plant the virus does not travel in the transpiration or water stream, nor, indeed, does it normally enter the stream. If deliberately introduced into the xylem vessels, it cannot normally escape; it therefore does not produce the disease, unless and until

it is artificially liberated. In none of the experiments devised to test the point did virus enter an unbroken cell. Large quantities of virulent juice can be injected into the leaf of a plant through the stomata, but symptoms will not develop unless some of the cells are ruptured. The development of virus in the leaves of an infected plant is followed by considerable alteration in the enzyme content. The mechanism of respiration is also greatly affected. This is being investigated in detail, and the work is still incomplete, but it seems clear that one of the first effects of the entry of virus into the cell is a greatly enhanced respiration rate and a state of general excitation.

3. *The relation of Virus to Insect-vectors.* By the development of a technique for maintaining insects upon solutions apart from the plant, considerable control has been obtained over the conditions determining the infection of the insect. Data have been obtained as to the time required for dyes and other substances taken in by the alimentary canal to reach the salivary glands, information which is necessary for the correct evaluation of the incubation or non-infective period after the insect has fed upon diseased material. By use of this technique it has become possible to investigate such problems as the filterability of viruses which are not transmissible by juice, e.g. leaf-roll of potatoes, and to approach the question why one insect carries and another does not.

A new virus disease has been discovered in *Hyoscyamus*, which is readily transmitted both by needle and by aphis, and has an incubation period in the insect. At the same time, at least two other unrecorded virus diseases were distinguished in commercial crops of this plant. These may prove to be due to viruses already better known in other crops, e.g. potato; and there is reason to believe that one at least of these new diseases is a composite disease caused by the simultaneous action of two different viruses.

BACTERIAL DISEASES OF PLANTS

The angular leaf-spot or " black-arm " disease of cotton is being investigated by R. H. Stoughton in considerable detail, because of its importance in many of the tropical cotton-growing countries of the Empire. The results have proved to be unusually interesting.

The responsible organism, *Bacterium malvacearum*, is of great bacteriological interest, as it possesses a nucleus and forms accessary reproductive bodies never previously described in this group of bacteria. It appears also to pass through a conjugation stage in which two cells join together to form a fusion-body or zygospore, of possibly different potentialities. It also " dissociates " or breaks down into a number of strains, quite unlike in pure culture and having different degrees of virulence. Strongly virulent strains may give rise to almost non-virulent ones, and these again revert to the culturally-unlike virulent form. The possible relation of this production of variants to the life history is now being studied.

The geographical and climatic distribution of the disease indicate that meteorological factors play a large part in determining its severity. Careful study has therefore been made of the separate effects of air temperature, soil temperature and air humidity.

Cotton plants were grown in special chambers in which these three factors are controlled automatically over a wide range so that each can be kept constant or made to vary uniformly as desired. The plants are grown entirely by artificial light, so that experiments at different times of the year are strictly comparable.

Air temperature plays the chief part in the development, as distinct from the spread, of the disease. Black-arm is essentially a high temperature malady, and in the control chambers severe secondary infection of the growing plant by spraying with a virulent culture is only obtained at temperatures above 30°C. The physiological reasons underlying this are under investigation ; they appear to be bound up with the relative rates of growth of the parasite and the plant, and the carbohydrate metabolism of the plant as shown by its sugar content. Fluctuating temperatures, whether soil or air, which resemble more closely natural conditions, give the same result as a constant temperature near the mean of the varying factor.

Soil temperature is less important. It plays, however, some part in determining the amount of disease on the very young seedlings grown from infected seed. The amount of this primary infection is reduced by high soil temperatures, e.g. above 30 C., but not sufficiently to offer any prospect of control by this method.

Air humidity is the chief factor determining the spread of the disease, but it is important only during the short period required for inoculation. Humid conditions are necessary for successful penetration of the tissues by the bacteria on the surface, however they have got there, but once penetration has been effected the external humidity has little direct effect.

Internal infection of seed, which has been suggested as a serious cause of primary infection, was found to be very rare ; external infection is the usual source. The primary infection can be controlled and healthy seedlings raised by complete sterilisation of the outside of the seed, indicating that the organisms are usually carried on the fuzz of the seed coat.

The costly appliances needed for this work were purchased and are maintained out of grants made by the Empire Marketing Board.

FUNGUS DISEASES OF PLANTS

W. B. Brierley continued his study of racial problems in fungi. A number of natural infections of different hosts by *Botrytis cinerea* were intensively analysed and, with few exceptions, two or more races of the parasite were obtained from any single lesion. In certain cases the fungus produced infections which could not be distinguished from each other but the host lesions contained populations consisting of different races or of assortments of the same races in different proportions. This method of intensive analysis was extended to other fungal parasites with similar results, and it seems possible that, in many diseases, infection may be caused by genetically complex populations rather than by single races of specific fungi.

Numerous experiments designed to study the educability of individual races of *Botrytis cinerea* produced no evidence of change lasting beyond the one generation.

M. D. Glynne continued her study of the wart disease of potatoes. Among varieties which, on the basis of field trials, have been officially certified as immune are some which, under the more stringent conditions of laboratory testing, develop small infections. The development of the parasite has been traced in a number of these varieties and, in some, the increase of the disease seems to be prevented by the development of a necrotic area in the region of infection by which the plant sloughs off the parasite with the dead tissues.

Critical examination of doubtful specimens of wart disease has been continued for the Ministry of Agriculture and the National Institute of Agricultural Botany and reports have been made on seventy-four specimens belonging to thirty-seven varieties.

Investigations into the relation of nutrition to certain fungal diseases of the potato plant by L. M. J. Kramer, at Rothamsted and at Woburn, showed no correlation between manurial treatment and the severity of attack by blight (*Phytophthora infestans*). The distribution of the disease was determined by the direction of the prevailing wind and the presence of infective centres.

Pot culture experiments, however, showed that excessive applications of phosphatic fertilisers increased infection of tubers by pink rot (*Phytophthora erythroseptica*).

A method of assessing the extent of fungal invasion of potato tubers was devised which corrects for the errors due to the size of the tuber. It has been extensively used and is of wide application.

THE INSECT PESTS

Wheat Midges. Observations made by H F. Barnes during the past five years on the incidence of wheat blossom midges on Broadbalk, combined with studies of the records of the Ministry's entomological advisors, have revealed some degree of periodicity in their attack. About every fourth or fifth year they do great damage to wheat, but in the intervening years the damage is insufficient to warrant any expenditure on control measures. The figures for the damage on Broadbalk for the last five years are :

Year.	1927	1928	1929	1930	1931
Percentage of damage to grain	3.2	6.5	7.7	17.6	21.4

Thus 1930 and 1931 were years of great damage on Broadbalk. The Ministry's records show that 1916, 1920 and 1926 were also peak years of damage. H. F. Barnes is following up these remarkable observations. If they lead to forecasting of attack some valuable practical results might be expected to emerge.

Varieties of Plants immune to insect attack. Agricultural pests are not easily controlled by direct methods such as spraying, which is so effective for hops and fruit. Indirect methods, including the use of resistant or immune varieties, are more suitable.

H. F. Barnes has continued his search for varieties of willows immune to gall midge attack ; this year he has concentrated on the midge that attacks the cricket bat willow (*S. coerulea*) which causes serious loss of sets, and has found certain basket willows immune to attack.

M. E. Metcalfe has been doing similar work on clovers and grasses, such as timothy, rye grasses and cocksfoot. All varieties of red clover are as a rule attacked by the red clover seed midge, but the white clovers are not. The extent of damage depends on the time of flowering of the clovers; possibly it could be avoided by delaying flowering until the flight of midges is over.

H. C. F. Newton is investigating the causes of plant immunity, and has begun a series of amputation experiments to ascertain which organ or organs on the insect enables it to differentiate between the varieties of plants.

The Pigmy Mangold Beetle (*Atomaria linearis*) has of late years been a troublesome pest of mangolds, but its life history could not be worked out because neither the eggs nor the larvae could be found in the soil. This has now been done by H. C. F. Newton, so that further knowledge of the pest can be obtained which may lead to the discovery of suitable remedies.

Other Activities. The department has kept in touch with the problems in the British Empire, and during 1931 has helped by identifying gall midges, on which H. F. Barnes is a recognised specialist, from Trinidad, Brazil, Algiers, Russia, Germany, Sicily, Cyprus, Turkey, Sierra Leone, Uganda, Nigeria, Malay and Formosa.

INSECTICIDES

Pyrethrum. For some years past F. Tattersfield and J. T. Martin have closely studied pyrethrum (*Chrysanthemum cinerariaefolium*), the flowers of which when dried and ground, form one of the most effective and convenient of all insecticides. Its popularity may be gauged from the fact that its production in Japan, the chief source of supply, rose from 279,931 lb. in 1911 to 11,622,906 lb. in 1928; its cultivation has also been started in France, Switzerland, Spain and the Argentine. Attempts are being made in conjunction with J. C. F. Fryer, of the Ministry of Agriculture to develop pyrethrum growing in this country; the results are distinctly promising. A very poor sandy soil gave an excellent sample. The manurial treatments so far tried have not markedly affected either yield or toxic quality of the flowers.

Climatic factors are, however, important. In tropical countries Uganda, Tanganyika and Trinidad, the plant grows but will not produce flowers; on the uplands of Kenya, however, good crops of flowers of high toxic value were obtained. In temperate conditions the number and the pyrethrin content of the flowers are reduced by reducing the illumination (e.g. by cutting off the hours of daylight) and finally with sufficiently low illumination (1,000 watt lamp only), no flowers are produced.

The toxic properties are due to two closely allied substances called pyrethrin I and II, which are esters of a ketonic alcohol, pyrethrolone, and two acids, one monobasic and the other dibasic. Neither the pyrethrolone nor the acids are toxic, only the combination of the two. The pyrethrin content of the flower heads depends on the plant; the order of merit of the different plants tested has been much the same in each of the three years of the experiment. There is some evidence that cuttings from high yielding plants will in turn produce high pyrethrin yields, though whether the property is transmissible by breeding is not yet certain.

Hitherto pyrethrum (made up as talc-pyrethrum dust) has suffered from the serious drawback that it is liable to lose its toxicity after a time. F. Tattersfield finds that the cause of the loss is oxidation of the poisonous principle, and this is specially marked in the light ; it is much slower in the dark. The loss is greatly reduced, however, by adding small quantities of certain antioxidants such as pyrocatechol, resorcinol, hydroquinone, pyrogallol and tannic acid ; on the other hand phenol and phloroglucinol were less effective.

Fish-poison Plants. A number of plants are used by the natives of tropical countries for catching fish by poisoning them. Many of these plants have been examined by F. Tattersfield and found to contain one of the most potent insecticides known, rotenone. Derris is the best known of these plants ; its root, which is the most effective part, usually contains some 2 or 3 per cent. of rotenone ; the quantity is variable, however, and in samples received in our laboratory it has ranged from 1 to nearly 6 per cent. Another plant, "cubé," *Lonchocarpus nicou* from Peru, contained as much as 6.4 per cent.

Certain other plants were found also to possess insecticidal properties, among them *Mundulea suberosa*, from India, and *Neorautanenia fisifolia*, from S. Rhodesia, but they seem less effective than the Derris and Haiari groups.

These insecticidal plants have undoubtedly a great future. They are far and away the best and safest insecticides and are very potent both against animal pests and against plant pests. The pyrethrin producers can be grown at home, and the rotenone producers in our tropical empire, notably in Malaya and British Guiana, and their cultivation would open up the possibility of an important new industry. F. Tattersfield has been highly successful in studying these plants, and it is deplorable that the work has had to be curtailed owing to reduction of grants just as it was beginning to yield results. It would have suffered much more but for the public spirited action of Mr. George Monro, who induced his company to make a grant of £100 for three years in order to keep the investigation going in readiness for active development whenever the opportunity arises. The Empire Marketing Board out of its slender resources made a grant of £50 to enable us to examine in detail some of the samples now being grown experimentally in British Guiana.

BEE RESEARCH

An important investigation into the causes of swarming has been begun by D. M. Morland. Young bees are hatched out in an incubator in weekly batches of 1,000 ; they are marked with distinctive marks and introduced into an observation hive ; their subsequent careers are then observed. They all go through a definite course. For the first part of their lives they act as wet nurses to the brood—the young larvae that will shortly become bees. Then, after a time, they pass on to household duties, such as the cleaning and ventilation of the hive. Still later they become food finders, going out foraging for nectar.

All goes well so long as the number of larvae is enough to keep the nurses fully occupied. But in late spring the number of eggs laid is very high, and each egg may in 21 days become a wet nurse seeking larvae to feed. As the number of eggs becomes less the number of larvae falls off, and then the nurse bees, apparently as the only way of using up their superfluous food and energy, start producing queen cells.

This causes trouble. The queen cells disturb the old queen, and when the next queen emerges, and in some instances even before she comes out, the old queen goes off with many followers. Swarming was induced in the experimental hive by introducing a host of active nurse bees ; a few days before the migrants left home some of them were seen three-quarters of a mile away, preparing an empty hive for occupation. When finally the swarm went off it took with it bees of the different categories—nursemaids, housemaids and food-finders—in approximately the same proportion as in the parent hive.

This work is being actively developed, but it needs more helpers. It is one of the most fascinating branches of social biology.

In addition, a number of investigations are made with questions of purely technical interest, though of great practical importance. Chief among these are the methods of ventilating the hive. Bee-keepers had been divided on this subject ; some had advocated the setting of the combs parallel to the front of the hive ; others preferred to set them at right angles, supposing that this would give better ventilation and freer access to the combs ; this way called the " cold way," in contradistinction to the other or " warm way."

Observations over a number of years have shown that neither arrangement has much effect on the temperature ; the bees manage this for themselves. During summer they completely control the temperature of the brood nest by fanning with their wings and during winter they completely control the temperature of the interior of the cluster by their own body warmth.

Warm air is expelled by the bees during the active season, especially in the process of ripening honey, but in winter the chief loss of heat from a hive occurs through the walls, by conduction. This is so important that special studies have been made to see how to minimise it. An outer cover was made giving a space of 6 or 8 inches all round the brood chamber, this space was filled with planed shavings. This additional protection improved the brood rearing conditions in spring and autumn, greatly reduced the consumption of stores in winter and afforded drier conditions in winter by eliminating condensation.

The omission of the shavings, as in the " W. B. C." hive, reduced the efficiency of the cover ; the temperature in winter was no better than in the single walled hive.

The moisture evaporating from the bees gives rise to important problems in hive construction. It penetrates the wall of the hive, but if the outside of the wall is painted it is held back by the paint forming a water blister. This penetration could not be stopped by coating the inside of the wall either with boiled oil or with the varnish gathered and applied by the bees themselves. If, however, the outside is not painted but only creosoted the moisture escapes. In winter this led to the bees clustering well forward against the warm south side of the hive instead of retiring on their stores in the normal way ; further, on sunny days in winter the bees flew while those in the white painted hives remained quiet. In summer, however, the creosoted hives were unbearably hot to the hand. The bees were quite equal to the emergency, and they kept down the temperature to the proper degree by fanning.

Unpainted zinc was an effective roofing material. Painted white, it remained very wet inside with condensed moisture during winter months, while painted black it became very hot in summer though it was always dry inside.

FUNGUS DISEASES OF CROPS ON EXPERIMENTAL PLOTS AT ROTHAMSTED AND WOBURN, 1931

M. D. Glynne

WHEAT

Mildew (*Erysiphe graminis DC.*) was first observed in June, and was most plentiful in July. It was generally slight, but in Little Hoos Top Dressing experiment at Rothamsted and in the New Rotation experiment on Stackyard field at Woburn the disease was moderate to plentiful.

Whiteheads (Take-all) (*Ophiobolus graminis* Sacc.) was first observed in May. The severity of the attack varied considerably from field to field and from plot to plot. It was more common on wheat grown continuously or in alternate years on the same land than when longer intervals occurred between each wheat crop. On Broadbalk the disease appeared to be rather more plentiful on the badly nourished plots 3—5 than on the others. It was considerably more plentiful at Woburn than at Rothamsted.

The permanent wheat plots on Stackyard Field, Woburn, showed such great differences in the incidence of disease on differently manured plots that a detailed survey was made which will be published later. On plots with a high degree of soil acidity the disease was absent or very much less than on those with a higher pH.

Loose Smut (*Ustilago Tritici.* (Pers.) Jens.) This occurred on several plots of Broadbalk. At Woburn it was found on the Continuous Wheat in Stackyard Field and on the Green Manuring Experiment in Lansome Field. It was also present on the variety Square Heads Master, but not on Yeoman II in the Precision Wheat Experiment on Lansome. Its incidence was slight.

Yellow Rust (*Puccinia glumarum*, (Schm.), Erikss. and Henn.) Was observed as slight in early June but increased as the season advanced. The attack varied from field to field, and from plot to plot, and on the whole was more abundant where the crop was heavy. In Woburn, on the Precision Wheat, it was more abundant on Square Heads Master than on Yeoman II, especially early in the season. It was very plentiful on Winter Wheat Var., Wilhelmina sown in July on Fosters Field, especially in September, when the leaves looked yellow with rust. In October, however, though the older leaves were still badly affected, the younger ones were green and appeared to be growing away from the disease.

Brown Rust (*Puccinia triticina* Erikss). Very plentiful in September on Winter Wheat, var., Wilhelmina sown in July, in Fosters Field. In October the plants appeared to be growing away from the disease, as the young leaves were very much less badly affected than the old ones.

Leaf Spot (*Septoria Tritici* Desm). Was found on all the wheat fields ; its incidence was on the whole slight.

Foot Rot (*Fusarium sp.*). Was found on the underground parts of the wheat plants as a white mycelium. Its incidence was very

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slight at Rothamsted, except on Hoos Field Wheat after Fallow, where it was present, though not plentiful.

At Woburn it was very slight on the Continuous Wheat on Stackyard, while on the Green Crops as Manures in the same field it was more plentiful, though still slight. It contrasted with Whiteheads, which was very plentiful on some plots of Continuous Wheat and very slight on the Green Crops as Manures.

OATS

MILDEW (*Erysiphe graminis, DC.*). Was found much more abundantly on the spring-sown than on the winter oats. The attack was especially heavy on the dark green, well-nourished plants. It was found fairly plentifully on Great Harpenden, Pastures and Broadbalk spring oats, and was present but not plentiful on the winter oats on Great Harpenden and Little Hoos fields.

LOOSE SMUT (*Ustilago Avenae* (Pers.), Jens.. Was found in the winter oats from June onwards. It was scattered through the crops and was fairly plentiful in Great Harpenden, in Little Hoos, and at Woburn in Lansome Field. It was not found on the spring oats.

CROWN RUST (*Puccinia Lolii* Niels). Was slight early in the season, and by August was fairly plentiful on the spring oats. It was also found in September and October fairly commonly on oats sown in Fosters Field in July.

LEAF SPOT (*Helminthosporium Avenae* (Bri. and Cav.), Eid.) Was found on both spring and winter oats at Rothamsted and Woburn, varying in quantity from slight to moderate. In no case did it appear to do much damage.

BARLEY

MILDEW (*Erysiphe graminis, DC.*). Was found on most of the barley, in greatest quantity on the plots receiving heavy application of nitrogenous manure.

WHITEHEADS (TAKE-ALL) (*Ophiobolus graminis*, Sacc.). Was observed on the Continuous barley in Stackyard Field at Woburn.

NET BLOTCH (*Pyrenophora teres* (Died.) Drechsl.). Was present in all the barley crops. It varied from slight to very plentiful on different fields at Rothamsted and Woburn.

BROWN RUST (*Puccinia anomala* Rostr.). Was generally fairly common. It was very heavy in September on barley sown in July in Fosters Field.

LEAF STRIPE (*Helminthosporium gramineum* Rabenh.). Was found on most of the barley crops at Rothamsted and Woburn, killing occasional plants. The loss due to the disease appeared to be slight.

While *H. gramineum* did not appear to cause much loss in the field, it did serious damage in many pot experiments. For work of this kind disinfection of seed is strongly recommended.

LEAF BLOTCH (*Rhynchosporium Secalis* (Oud.) Davis). Was found in most, but not all the barley fields. None was found on Long Hoos, Rotation ; it was most common on the Continuous barley in Hoos. At Woburn it was moderate on the Continuous barley in Stackyard and in the Rotation Cake v. Corn in Lansome Field. On most other barley plots it was slight.

RYE

Ergot (*Claviceps purpurea* (Fr.) Tul.). A little was found in August on the commercial rye grown for seed in Great Harpenden Field.

Brown Rust (*Puccinia secalina*, Grove). Was present but not very plentiful except on the rye sown in July in Fosters Field, where the attack was moderate.

Leaf Blotch (*Rhynchosporium Secalis* (Oud.) Davis). Was present in small quantity on Little Hoos and Great Harpenden Field at Rothamsted. On Butt Furlong Field at Woburn the attack was unusually severe.

RYE GRASS

Ergot (*Claviceps purpurea* (Fr.) Tul.). Was found occasionally on rye grass growing at the edge of Fosters Field.

Crown Rust (*Puccinia Lolii*. Niels). Was common in September on rye grass in the forage plots on Fosters Field.

GRASS PLOTS

Choke (*Epichloe typhina* (Fr.) Tul.). A detailed eye estimation of the amount of this disease was made on all plots on June 23rd, 1931, and checked on the following day. *Epichloe typhina* was found generally on Agrostis and very occasionally on *Dactylis glomerata*. It varied considerably from plot to plot, as has been observed for many years. Liming appeared to reduce the disease, and ammonium sulphate even after it had been discontinued for many years, appeared to increase the disease except in the limed parts. Plots 11-1 and 11-2, which receive treble ammonium salts, had little disease, but there was very little Agrostis in these plots except at the edges and these plants were considerably affected.

A potash deficiency has long been regarded as a predisposing cause for this disease. A careful comparison of comparable plots with and without potash 5-2 and 5-1, 7 and 8, 9 and 10, showed similar amounts of disease in the individuals of each pair of plots except in 9 and 10. Plot 10, which lacks potash, had more *Agrostis* and more *Epichloe* than 9, but the proportion of *Epichloe* to *Agrostis* appeared similar in each plot. This observation should be repeated over a number of years.

The distribution of the disease must necessarily be partly depedent on that of *Agrostis*, and this varies very much with manurial treatment. There is, however, some evidence which suggests that the distribution of Choke varies on plots in which the amount of *Agrostis* is similar. In order to assess the parts played by the distribution of *Agrostis*, the direct effect of manurial treatment and other factors, on the incidence of the disease considerably more data are needed.

BROAD BEAN

(On Great Knott Field, Rothamsted)

Chocolate Spot (*probably Bacillus Lathyri* Manns and Taub.). Very common.

Rust (*Uromyces Fabae* (Pers.) de Bary). Very common.

Grey Mould (*Botrytis cinerea*, Pers.). Very common, occasional plants apparently killed by it.

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SWEDE

FINGER-AND-TOE (*Plasmodiophora Brassicae* Woron.). Was found on Barnfield, but was not common.

MILDEW (*Erysiphe Polygoni*, DC.). Fairly common.

MANGOLD

RUST (*Uromyces Betae* (Pers.) Tul.). Was found fairly frequently on Barnfield in October.

BLACK LEG (*Phoma Betae* (Oud.) Frank). Was found on Barnfield on young plants in June, in moderate quantity. Affected roots were found but were not common at harvest.

LEAF SCORCH (*possibly non-parasitic*). Was common on plots in Barnfield in October. It was on the whole more plentiful in plots which received nitrogen as manure than in those which did not.

SUGAR BEET

CROWN GALL (*Bacterium tumefaciens* E.F. Sm. and Towns). Was found on a few roots at Rothamsted. It was uncommon, but occasionally well developed.

RUST (*Uromyces Betae* (Pers.) Tul.). Was found occasionally in the sugar beet at Rothamsted. The attack was slight.

LEAF SCORCH (*possibly non-parasitic*). Was common both at Rothamsted and Woburn. At Rothamsted, on Rotation II on Long Hoos, it was fairly evenly distributed, and was moderate to plentiful on every plot. The difference in manurial treatment did not appear to affect the incidence of the disease.

At Woburn, on the Manurial and Cultivation Experiments on Butt Furlong Field, it varied considerably from plot to plot. Counts were therefore made of the number of plants showing " scorch " on the micro-plots and on the plots in four blocks of the main experiment.

There was some indication on the main experiment that late application of manure and the addition of sulphate increased the disease and rotary tillage reduced it. On the micro-plots, however, the addition of sulphate did not appear to increase the disease, which was on an average greatest on the unmanured plot.

REPORT ON INSECT PESTS OF THE ROTHAMSTED FARM, 1930-1931

By H. C. F. NEWTON

GENERAL. One of the most notable features on the Rothamsted farm this year was the almost complete absence of damage to the cruciferous crops by Flea-beetles (*Phyllotreta* spp.), although last year two, and in some parts of the fields three, sowings had to be made to get a plant.

Insect fluctuations and their causes are receiving an increasing amount of attention by entomologists. Very little is known about flea-beetle attacks, beyond the broad generalisation that a dry hot spell favours attack. Wet weather may be disastrous, in spite of general opinion to the contrary, provided the temperature be not too low. The attack, however, is not determined only by the weather prevailing at the time, but also by the character of the winter, for the damage is done by beetles that developed during the previous summer and survived the winter as adults.

Very little is known about the parasitism of the *Phyllotreta* spp. One of them, *P. nemorum*, passes through its developmental stages above ground and can be heavily parasitised; the other species are all underground during development, and as far as is known suffer but little parasitisation; and as these usually far outnumber *P. nemorum*, it appears unlikely that parasitisation can be an important factor in causing the enormous fluctuations in numbers recently witnessed on the farm.

Frit Fly (*Oscinella* (*Oscinis*) *frit Linn.*). This year an unusual and widespread attack on the winter cereals by " frit " took place during the months November-January. The maximum emergence of the last flight occurs about the months of August-September, but the cereals attacked were not sown till the middle of October, and of course grew up much later. There is thus a period of some weeks between the time when the flies are ovipositing and when the cereals could become infected. It is probable that the volunteer corn, which came up plentifully after the wet harvesting conditions, maintained the frit larvae in the interval, the young corn being infected from this source. The actual dates are as follows for Broadbalk, 1930:

Cutting wheat . . .	August 18th
Cultivation . . .	August 30th
Ploughing operations . .	October 3rd—14th
Wheat drilled . . .	October 16th*

There was therefore a period of nearly six weeks during which ample opportunity for infestation of volunteer corn occurred; between final ploughing and seeding only a very short interval.

The spring attack of Frit fly was below normal.

Wireworm (*Agriotes spp.*). Damage due to this pest was unusually bad on the classical barley plots, and is dealt with more fully in a later paragraph.

BROADBALK

Wheat

The Frit fly (*Oscinella* (*Oscinis*) *frit* Linn. An examination of brown discoloured shoots observed at the end of November revealed the presence of Frit fly larvae. The attack was spread generally over the field and was in places severe. A number of observations were made to discover (*a*) the percentage of attack; (*b*) the number of attacked plants that recovered; and (*c*) the spread of the infestation during the period under observation.

A number of random square yards were pegged out, and the number of dead, attacked but living, and unattacked plants were counted at intervals.

The counts on November 22nd and mid-December were, when expressed as numbers of attacked plants per acre :

* For the present season the dates are as follows: 1931. Cutting, August 18th; ploughing operations begun August 29th and continued till September 15th; cultivations, September 21st, September 26th and October 10th—12th; seeding, October 13th. A search for frit-infested plants during the last month (November-December, 1931) has been almost entirely fruitless. In the absence of relevant data concerning the numbers of the last flight of frit in the two years it is not claimed that the difference in the cultural methods is wholly responsible for the difference in attack, but it is certainly suggestive. The matter could be simply settled by keeping an area of the field free from volunteer corn.

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	November 22nd.	Mid December
Plot 2	22,448	96,800
„ 3	10,164	48,400
„ 5	4,840	34,848
„ 6	10,300	61,952
„ 7	14,036	—
„ 8	8,712	—
„ 13	—	40,072

The total number of plants per acre was about a million.

The worst attack encountered was in Plot 2 (farmyard manure), and affects just under 10 per cent. of the total plant population.

There is no correlation of attacks with manurial treatment, but the highest infestation was on an area in the Farmyard Manure Plot, 38 plants to the square yard, or nearly 15 per cent. Seventy per cent. of the plants marked as " dead " had not recovered up to the beginning of January. Whether the plant dies or not depends on how far the grub eats out the central shoot. In wet weather the plant frequently rots and is invaded by secondary parasites, e.g. mites and nematodes which complete the disintegrating process. Plants attacked just after germination and during the next month or so rarely recover ; after January the plants can resist the attack.

Wheat Bulb Fly (*Hylemyia coarctata* Fall.) This fly was present, but did no appreciable damage. Another dipterous larvae causing similar damage was also present, and is being investigated. This fly would appear to occur rather later than the bulb fly, as larvae not fully developed were found as late as the middle of May.

Leaf Miner (*Agromyza sp.*). This fly was much less plentiful than last year and damage was small. Most of the mines were inhabited by one larvae, but many with 2, 3 and sometimes 4, were found. Occasionally also, pupation takes place within the leaf instead of in the ground. Material has been collected to find out if more than one species is present, and to see what parasites—if any —emerge.

Midges (*Contarinia tritici* Kirby, *Sitodiplosis mosellana* Géhin.). The midge attack was the worst observed during the last five years. Parasitism was very heavy, in some cases the ears being at times almost black with ovipositing parasites.

The Wheat-stem Borer (*Cephus pigmæus* Linn.). This was again present, but damage was estimated *nil.*

Pheasants. A good deal of injury was caused by pheasants in the early winter.

Timothy Grass

The ears of the Timothy grass in the borders around Broadbalk were much attacked by the Timothy fly (*Amaurosoma* sp.).

GREAT HOOS FIELD

Classical Barley Plots

Wireworm (*Agriotes* spp.). The most notable feature of the year was an attack by wireworm. It was first observed on May 6th and by May 13th the rows of barley on some of the plots looked as if a fire had swept across them. The attack was most noticeable on the unmanured or incompletely manured plots, and on the worst of these, 6-1, 50 per cent. of the plants showed signs of attack and many were killed. On the completely manured plots the plants were better able to keep pace with the damage, but even here many gaps were made. By the end of June the surviving plants had outgrown the attack.

The relative damage on the different plots was as follows: (1) being the most damaged; (4) the least; in each category the plots are arranged in the order of the damage done:

1. 6-1 (most damage), 4, 3, 6-2, 3A, 1.
2. 7-1, 7-2, 4A, 1A, 1AA.
3. 2, 4AA, 3AA, 1AA.
4. 2AA, 2A, Rape Cake Plots (least damage).

The order in which the plots recovered was as follows, (1) being the quickest and (4) the slowest:

1. 7-2 (recovery quickest) Rape Cake Plots, 4A.
2. 2AA, 4AA, 2A, 3AA, 1AA.
3. 7-1, 4, 3, 2, 1.
4. 6-1 (recovery slowest).

This order corresponds fairly well with that of the average yields.

THE GOUT FLY (*Chlorops taeniopus* Meig.) was present as usual, but the attack was less than last year.

THRIPS. Frequently damaged the young ears, but not seriously.

FOUR COURSE ROTATION EXPERIMENT

WHEAT. *Cephus pigmæus* present.

Practically no leaf miner (*Agromyza* sp.).

SWEDES. This year there was no loss from flea-beetles (*Phyllotreta* spp.). A good deal of leaf damage to young plants was, however, caused by pigeons, June-July. An attack of mildew was encouraged by the late singling of the plants.

SEEDS AND BARLEY. No significant attacks.

ALTERNATE WHEAT EXPERIMENT

Early attack by Frit fly; wheat bulb fly (*Hylemyia coarctata* Fall), wheat midge and *Cephus pigmæus* all present. Leaf miner attack slight.

KALE

No flea-beetle attack.

SIX COURSE ROTATION

WHEAT. As expected, the wheat after fallow was attacked by wheat bulb fly during March and April. However, the wheat seeding had been so thick and so much early tillering had taken place before the attack began that no loss resulted. The number of tillers in a linear yard varied from 280 to 120, figures far in excess of those obtaining on Broadbalk. The average number of tillers attacked per linear yard was fifteen.

CHARLOCK PLOT. Larvae of *Chortophila brassicae* Bché occurred on the Charlock roots. This insect may be a serious pest of cultivated Cruciferae.

SUGAR BEET. *Atomaria linearis* Stephens, the Pigmy mangold beetle, was present but caused no loss of final "plant." The loss that occurred was probably due to hares. Only two larvae of *Pegomyia hyocyami* were seen at the end of June. Numbers of the Spotted Snake Millipede, *Blaniulus guttulatus* Bosc. were found usually in association with *Atomaria* ; the wounds caused by the one apparently attract the other.

BARLEY. There was slight wireworm attack in April and some damage by wheat bulb flies which must have been very late specimens. Frit and Gout fly attacks were insignificant. A few leaf miners were found similar to the *Agromyza* on wheat.

CLOVER. POTATOES. No significant attack.

FORAGE MIXTURES. Slight attack by wireworm (March-April) after bastard fallow. Wheat bulb fly killed many tillers during the same period ; in the worst cases as many as four out of six tillers were attacked.

No damage was observed on the Rye plots, nor the Linseed and Kale that followed.

LITTLE HOOS

FORAGE CROP EXPERIMENTS. Attack by the pea and bean weevils (*Sitona* spp.) occurred, but was much less serious than last year, when the crop was spring-sown and so less able to withstand damage. An autumn attack by Frit fly occurred.

WHEAT EXPERIMENTS. The autumn early winter attack by Frit fly was general.

GREAT HARPENDEN

SPRING OATS. A rather bad attack by wireworm occurred generally during April, and this, together with the rooks, depleted the plant. Spring Frit fly attack was small, but there was occasional damage by a lepidopterous larva, probably *Apamea secalis* Bjerk.

WINTER OATS. A slight attack of wireworm occurred during the spring following the early winter Frit fly attack.

WHEAT VARIETY TRIALS AND RYE PLOTS. In early winter there was an attack of Frit fly generally. Some plants when about 1 foot high had the central shoot killed by *Apamea secalis* Bjerk.

MICRO SUGAR BEET PLOTS. *Atomaria linearis* Stephens was the chief pest here, but the sugar beet had been " dibbled " in, some 5 or 6 seeds to a hole, so that though some plants were destroyed the final stand was not affected. Observations made on the life history of this beetle are being published (*Ann. Appl. Biol.*, Feb., 1932). Surrounding dock plants were much eaten by *Plectroscelis concinna* Marsh, but no damage to beet plants was noticed.

BARNFIELD

Atomaria attacked the mangolds in early May, but the numbers were insufficient to account for the failure of the first sowing, which appeared to be due in part to cultural conditions. Only one *Plectroscelis concinna* was seen, and there was no evidence of attack by this beetle.

The second sowing did not appear to suffer from attack except for a strip along the west side of Plots 1C, 1AC and 1A, where the mangolds were taken but not the swedes. Pigeons probably did much of the damage, but earwigs were also plentiful, obtaining shelter from the grass banks at the side and perhaps from the chicken pens. Three earwigs captured from the plants at night were kept in the laboratory confined with 2 swede and 3 mangold plants. Within 5 days the plants were destroyed but no preference was shown.

WOBURN

An attack on the micro-plots of sugar beet was the only thing of interest this year. Only a few plants were lost, the stems being eaten off a short distance above ground level with a short length of the central strand left. Mammals or birds are suspected. A *Harpalus* was collected by spreading sacking at night, but no damage could be ascribed to this insect.

FIELD PLOT TECHNIQUE

The Statistical Department has been largely concerned with the methods of the interpretation of field and laboratory experiments, and with the principles of their design. The principles which govern the dependence of interpretation on design have been made clear in previous years. Many voluntary workers, however, are anxious to illustrate particular aspects of these principles and to explore further the practical bearing of the observations made in uniformity trials and in explicit experimentation.

During the year three workers (F. R. Immer, S. H. Justensen and R. J. Kalamkar) have taken up the question of the most efficient use of land in experiments in which an edge row must be discarded. In such cases the narrower the strip used as a plot, the larger the proportion of the crop rejected from the experimental data. On the other hand, it has been widely verified that, for the same area harvested, subdivision into numerous small plots generally leads to a considerable increase in precision. Using independent data relating in two cases to potatoes and in one to sugar beet, each enquiry showed that the best use of a given area can be made by using 4-row plots, where half the total area is discarded. Consequently where the precision of the experiments is chiefly restricted by the experimental area available, this width of plot may be expected to give the best results.

The efficiency of the sampling method, both in its application to yield trials and to the progress and growth of crops, largely depends on the choice of the sampling unit, or set of drill lengths fixed by a single act of randomisation. Experience in previous years had thrown doubt upon whether the form of sampling unit originally chosen for crop weather observations was the best possible: (1) because the 4 quarter metres of which it was composed were all taken from the same drill row, and as had been first shown by Clapham, lengths from the same drill row were somewhat highly correlated; (2) because it was doubtful if any additional precision was gained by spreading the sampling unit over a length of 10 feet, when probably there was a real competition between the growth of parallel adjacent rows. By harvesting a small area completely in ½-metre lengths, Kalamkar was able to test experimentally the efficiency of different forms of sampling unit, with the result that a unit of four parallel lengths on adjacent rows was found to be actually the most efficient. Since this form of unit is very convenient to take in the field, and in the crop weather observations can be used to simplify the whole sampling procedure, its use in future is to be recommended.

As the existence of an accurate theory of small samples has come to be known, mathematical statisticians on both sides of the Atlantic have devoted much work to investigations by experimental sampling. Much of this work has been aimed at solving (practically) somewhat abstract problems of distribution, which presented analytical difficulties to the mathematician. Rightly approached, however, the subject has a practical and scientific interest, for the experimenter in designing his experiments will want to know whether the analysis of variance, or one of the tests which are particular cases of this analysis, will, without additional precautions, be sufficiently applicable to his material, even if it exhibits anomalies of the third degree, such as skewness, correlation of mean with variance, etc. An extensive sampling experiment has recently been carried out by T. Eden, to test whether the analysis of variance, applied to a randomised blocks *schema*, on such skew material, would in fact indicate the true limits of significance. The distribution of 1,000 tests of significance was found to be in complete conformity with theoretical expectation for normal data.

The analysis of variance has not, however, always been rightly applied. The great simplicity of the arithmetical processes, when applied to experiments designed to secure this simplicity, has sometimes led to a neglect of the fact that any interactions which, as is often advantageous, have been confounded with components of soil heterogeneity, or which, as is usually less satisfactory, are between non-orthogonal sets of treatments, as in many of the older types of experiment, require special care to obtain the true estimate of error. Through neglect of this precaution the interpretation to be placed on two of our previous experiments in 1929 and 1930 have been revised in the current report (p. 150 ; p. 156). Although no important conclusions, but only the significance of certain manurial interactions, are affected, the point is one which deserves attention, as it is very liable to give trouble to inexperienced computers, and should especially be considered in experimental design.

An increasingly important aspect of the application of the principles of experimental design, concerns the design of co-ordinated experiments carried out at a number of centres. During the year two workers from Canada have been working on these problems, and a report with recommendations has been made by J. W. Hopkins to the National Research Council of the Dominion, on their co-operative experiments on the influence of seed rate on the yield of varieties of oats. Professor Summerby also was engaged in the design of comprehensive manurial experiments on fields under rotation.

In the field of Agricultural Meteorology, A. L. Murray, of Dublin, has taken up the question of the interpretation of the heavy loss in wheat yield from Broadbalk, ascribable to winter rain ; finding, contrary to expectation, that this loss is not to be avoided by using spring in place of autumn dressings of nitrogeneous fertilisers. The spring dressed plots show, however, an advantage in years with a wet summer. The classical experiment with mangolds, on Barnfield, has been analysed by R. J. Kalamkar, in connection with the amount and distribution of the rainfall. The yields from these plots are, however, so variable that it would be unsafe as yet to interpret the

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data, until the influence of varying root number has been separately assessed.

The year has seen considerable progress in theory, especially in regard to the analysis of covariance, as well as in the practice of its various applications.

THE ACCURACY OF THE FIELD EXPERIMENTS

The standard errors per plot of experiments carried out in 1931 are given in Tables X, XI and XII together with an average of those obtained in previous years. It will be seen that these errors are of the same magnitude as in previous years, and that there is little difference in the accuracy obtained at Rothamsted and the outside centres.

TABLE X.

STANDARD ERRORS PER PLOT, 1931.

Rothamsted.

Weight per acre.

	Potatoes. tons.	*Sugar* Roots. tons.	*Beet* Tops. tons.	*Barley.* Grain. cwt.	Straw. cwt.	*Wheat.* Grain. cwt.	Straw. cwt.
Latin Squares—							
Average 1925-1930 ..	0.4	0.6	0.7	1.3	1.9	—	—
1931	—	—	—	2.0	2.1	1.5	3.1
Randomised Blocks—							
Average 1925-1930 ..	0.7	0.3†	1.2†	1.5	1.9	2.9	4.3
1931	1.2	0.5	1.0	—	—	1.8 } 1.4 }	4.2 } 3.2 }

†Single figure.

	Oats. Grain. cwt.	Straw. cwt.	*Forage.* Hay. cwt.	Grain. cwt.	Straw. cwt.	*Hay.* cwt.
Latin Squares—						
Average 1925-1930	—	—	—	—	—	—
1931	—	—	4.2	2.4	3.6	3.1
Randomised Blocks—						
Average 1925-1930	—	—	—	—	—	—
1931	2.4	2.6	1.4	—	—	—

Per cent of Yield.

	Potatoes.	*Sugar* Roots.	*Beet.* Tops.	*Barley.* Grain.	Straw.	*Wheat.* Grain.	Straw.
Latin Squares—							
Average 1925-1930	4.4	5.7	5.6	5.6	7.4	—	—
1931 ..	—	—	—	12.4	9.4	8.3	8.7
Randomised Blocks							
Average 1925–1930	8.4	10.2*	10.9*	9.1	7.2	14.0	10.8
1931 ..	10.0	4.1	6.4	—	—	8.3 } 8.9 }	9.5 } 8.2 }

*Single figure.

	Oats. Grain.	Oats. Straw.	Oats. Hay.	Forage. Grain.	Forage. Straw.	Hay.
Latin Squares—						
Average 1925-1930	—	—	—	—	—	—
1931	—	—	8.2	12.2	7.8	7.9
Randomised Blocks—						
Average 1925–1930	—	—	—	—	—	—
1931	12.7	10.2	16.1	—	—	—

TABLE XI.

Woburn.

Weight per acre.

	Potatoes. tons.	*Sugar Beet.* Roots. tons.	*Sugar Beet.* Tops. tons.
Latin Squares—			
Average 1926-1930	0.5	1.3	1.1
1931	—	1.0	1.2
Randomised Blocks—			
Average 1926-1930	0.7	1.0	1.5
1931	—	1.3	2.6

Per cent. of Yield.

	Potatoes.	*Sugar Beet.* Roots.	*Sugar Beet.* Tops.
Latin Squares—			
Average 1926–1930	5.1	9.1	11.0
1931	—	8.4	7.3
Randomised Blocks—			
Average 1926–1930	8.7	12.5	19.1
1931	—	11.5	20.2

TABLE XII.

Average of Outside Centres.

Weight per acre.

	Potatoes. tons.	*Sugar Beet.* Roots. tons.	*Sugar Beet.* Tops. tons.	*Swedes.* Roots. tons.	*Swedes.* Tops. tons.	*Barley.* Grain. cwt.	*Barley.* Straw. cwt.	Hay. cwt.
Latin Squares—								
Average 1927-1930	0.6	0.6	0.8	—	—	1.5	1.4	2.1
1931 ..	0.6	0.6	1.1	1.7	0.2	—	—	3.6
Randomised Blocks								
Average 1927-1930	1.0	0.8	1.3	—	—	—	—	—
1931 ..	0.8	0.7	2.0	—	—	—	—	4.9

Per cent. of Yield.

	Potatoes.	Sugar Beet. Roots.	Sugar Beet. Tops.	Swedes. Roots.	Swedes. Tops.	Barley. Grain.	Barley. Straw	Hay
Latin Squares—								
Average 1927–1930	5.2	6.4	6.7	—	—	7.8	8.3	8.5
1931 ..	6.6	5.3	8.4	5.6	5.6	—	—	7.7
RandomisedBlocks—								
Average 1927–1930	9.0	7.4	8.2	—	—	—	—	—
1931 ..	10.2	5.8	10.3	—	—	—	—	10.9

FARM DIRECTOR'S REPORT, 1931

Weather. The general character of the weather is shown by the graph of deviations from average values (p. 62). The features of the year October, 1930—September, 1931 were the wet November and December, the mild winter and the cool, moist summer with a wet harvest. The mean temperatures for June, October and November were respectively 1°F., 2.1°F. and 0.3°F. above the 52 year average, but for all the other months it was under the average, the total deficit for the year being 7.1°F. The only really hot weather occurred between June 20th and July 10th.

There was very little frost apart from a fortnight of quite sharp weather at the end of February and beginning of March. This, along with occasional night frosts during the winter, brought the ploughed land to a good powdery tilth by the spring.

Every month from April to September experienced fewer hours of sunshine than the 38 year mean, the deficit totalling altogether 191.6 hours. October had 28 hours and March 38.7 hours above the mean.

5.1 inches of rain in November made the autumn very wet, but luckily this did not affect any of the farm work. July and August together had 2.1 inches rainfall above the 78 years average, but it was not the amount that made the bad harvest so much as the numerous small showers. The total for the year was 29.9 inches, being 1.15 inches above the mean.

Although the past season was wet and cool, yet October, 1930, and March, 1931, were unusually dry. In October, only 1.24 inches fell, against the average of 3.11 inches, and the drainage through 60 inches of bare soil was 0.211 inches as against the average of 1.63 inches for that month. In March the total rainfall was 0.09 inches, and measurable rain fell on two days only. The rainfall was the lowest shown in our 78 years records for March, except for March, 1929 (0.065 ins.), the lowest recorded figure for any month being 0.063 ins. in December, 1864.

Cropping, 1930-1932. (For dates, yield and other information, see pp. 109-114.)

Rye was sown in Long Hoos, Sections I, II and III, in September, 1930. This was fed off to sheep in March, 1931, and again in May. Sections I and III (old division) had previously been dunged just before sowing at the rate of 14 tons per acre. Section II had carried mustard folded off with sheep in August, 1930

Dung was carted out to Little Hoos in September, 1930, at the same rate ; this was the first application of dung since the termination in 1921 of the old experiments on residual values. Several good crops had been grown without dung. Forage and wheat were later sown in this field.

Beans were sown in Great Knott after wheat, on October 2nd, and proved successful, apart from some thin places due to damage by pigeons. Before harvest the plants were 6 feet high in many places. The lower portion of this field is still rather infertile, however, and the crop was distinctly lighter there.

All of the 1930 sugar beet and potatoes were out of the way before October, thus enabling the following crops to be sown early. Broadbalk was sown on October 16th. All the sowing was completed under favourable conditions, although rather later than in 1929 ; the ground was fairly moist, and not dusty as it had been for the preceding crops.

The kale in Pastures was used between the middle of December and the end of February, 1931 ; some was carted off to stock, the rest folded.

This folding caused some puddling ; nevertheless, the field after ploughing worked down to quite a favourable tilth. On part of the land Marvellous oats were sown ; the crop, however, was disappointing and much inferior to the mixture of barley with beans. Mayweed—usually, like iron grass (*Polygonium aviculare*), bad in this field—spread rapidly where the plant was thin. Another part of the land carried the 1931 experimental potatoes grown without dung ; the yields were amongst the heaviest obtained here. The old kale stems caused no difficulty in ploughing or sowing corn, but somewhat hindered the preparation of the potato ground.

Part of the Great Harpenden seeds ley was ploughed up in September and sown with Grey winter oats ; on the remainder sheep were fed during the winter, the land was ploughed in January, with narrow, well set-up furrows, and crumbled to an ideal tilth for spring oats after some frosts. Just after sowing, a sharp spell of frost occurred ; during this period crows attacked the seed, yet the crop was considerably heavier than the winter oats. Wireworm and crows both affected the spring oat experiment carried out on this area.*

One year seeds in Fosters yielded heavily, estimated at over 2 tons hay per acre. The crop, however, was used for stack silage because of the very showery weather. To it was added the produce from our rotation and forage experiments, making a total of about 100 tons of green matter. The final product was sweet, dark brown silage, much relished by stock. The waste round the outsides was smaller than anticipated ; it was roughly estimated at about 10 per cent. The outside material was carted to out-wintered cattle and the small amount they did not eat was tramped into the ground as

* The mean yields of the spring varieties were in cwt. per acre.

	Grain.	Straw.
Marvellous	19.6	24.6
Golden Rain II.	18.7	27.0
Victory	17.4	27.5

It is doubtful whether any of these differences are significant as the plots were not adequately replicated or randomised (p. 144) manure. Analyses showed, however, that in spite of the good appearance, the material contained much less protein than is usually found in farm crops.

Per cent. in sample as received.

	Protein	Fat	Soluble Carbo-hydrates	Fibre	Ash	Water
Silage from one year's seeds mixture	1.22	1.24	23.0	13.9	3.95	56.7
Silage from general forage mixture	1.22	0.96	16.2	10.7	2.52	68.4
Per cent. in Dry Matter						
Silage from one year's seeds mixture	2.82	2.86	53.1	32.1	9.12	—
Silage from general forage mixture	3.87	3.04	51.3	33.8	7.99	—

Oats and wheat (cut green) contain 6 to 7 per cent. of protein in the dry matter, while leguminous crops contain 17 to 20 per cent.

All the oats in Great Harpenden, winter and spring, were undersown in April, 1931, with 20 lb. Western Wolths Ryegrass and 5 lb. trefoil per acre. This is to be utilised for feeding sheep on during the winter, then it will be dunged and sown with kale.

Laid corn was a less serious problem than in the previous harvest The winter oats were worst, but the power-binder proved of great value in dealing with them. The Little Hoos wheat experiments were badly laid and had to be scythed, while several of the Broadbalk plots were also bad.

The weather seriously hindered the harvest, particularly from the plots. Threshing took a long time, and much of the produce had to be carted into the shelter of the Dutch Barn. By the end of harvest we were a full fortnight later with our general farm work than in previous years. Luckily a very fine spell of weather during October and part of November allowed us to catch up again.

After the ewes and lambs had used the Long Hoos rye (p. 57) it was ploughed up. Sections II and III were sown on May 7th, 1931, with linseed, which yielded 10 cwt. grain per acre. It is difficult to cut with the horse binder, but easy to manage with the power-binder. Section I was sown with kale on June 13th. It came well and did not suffer from the flea-beetle. Despite this and the excellent growing season, the final yield of 16-18 tons per acre was disappointing considering the autumn dung, manuring by sheep, and 2 cwt. sulphate of ammonia per acre ; in 1930 the yield had been 4 or 5 tons per acre higher.

Barnfield mangolds were sown on April 15th-17th. The seed went in deeply on a dusty tilth and germination was slow and uneven. They were therefore re-sown on May 26th, and gave a splendid plant and a splendid crop. A few swedes sown as a safeguard with the mangolds developed even better; their superior size compared with neighbouring mangolds was striking. In the dry autumn the crop was carted in ideal conditions, the land being much less cut up with the carting than usual. It was all ploughed, after applying dung to the proper plots, in this good condition. For two years now we have tried two different spacings on each of the plots. It was hoped that with narrower drills the foliage would more quickly grow over and check weeds ; instead, the low yielding plots where this effect was most desired, gave smaller plants than with wide spacing, thus defeating the object of the narrower drills.

In Agdell the wheat on the fallow half was very poor. On Plot 1C and on the top half of 3M the germination was very poor indeed. The seedlings appeared to be drowned by the rain before they were properly established.

Two observations in the Hoos Field Rotation were noteworthy. After the hay crop, the residual effect of all the manures, including dung and straw plus artificials on the following wheat was very slight. After the swede crop, however, the residual effect of straw plus artificials, which had greatly increased the yield of swede tops, was obviously greater than the direct effect of straw plus artificials applied direct to the barley, despite the very heavy dressing of nitrogen given ; the one plot was laid, the other was not to any extent.

On the other hand the direct effect of straw plus artificials on the hay crop was greater than the residual effect, and indeed exceeded the effect of any other treatment.

The forage experiment in Little Hoos gave high yields. The best plots could not well have been heavier, being about 6 feet high and almost lodging when cut green. The wheat mixtures seemed superior to the oats, the oats growing very slowly in the early summer; it was therefore surprising to find that the oat mixtures were the heavier after all. The half plots left till harvest were very badly laid and suffered from birds.

In July another forage experiment was started. Its aim was to explore the possibilities of producing early and later green crops so as to extend the operating season of a machine for drying green crops, which would deal chiefly with lucerne and grass in the main part of the season. The weather between July and November was more than usually favourable to growth, nevertheless the maximum autumn yield was only 7 tons of green matter per acre, no more than the much cheaper temporary grass growing nearby which, however, would have been more difficult to cut at that time of year. The experiment is continuing to the late spring of 1932.

Control of Black bent (*Alopecurus agrestis*), at present the worst weed on the arable land at Rothamsted. It is much worse in autumn sown crops—cereals and beans—than in those sown in spring. Several methods of reduction are being tried :

(1) Rye is grown as the winter cereal ; this is folded by sheep in spring and then ploughed under in April or May ; the *Alopecurus* seed can thus germinate, but the resulting plants can produce no fresh seed. Rye, however, has some drawbacks. It is more costly than certain other spring foods, and in 1931 it appeared to handicap the succeeding kale crop. This is being followed up experimentally.

(2) Spring oats are grown instead of winter oats. If this proved successful the sheep feed would be supplied by cheap one-year seeds mixtures or rape kale instead of green rye.

Grass. This was a most favourable season for grassland. Pastures continued green and in active growth throughout, although the start was slow, and for a fortnight at the beginning of July growth almost ceased. Sawyers I and III received 1 cwt. per acre nitrate of soda early in February to encourage an early spring bite ; the result, however, was very disappointing, there being very little early growth at all. Later on, however, this field provided excellent keep for the ewes and lambs. It was then shut up for only 6 weeks and gave a 30 cwt. crop of hay. Despite the nitrate and the haymaking, the Wild White clover formed a thick carpet in the aftermath.

All the other grass showed steady improvement under the favourable conditions and gave a splendid aftermath for the lambs and for flushing the ewes.

Live Stock. The chief development has been with sheep. Three investigations have been started :

(1) A study of the suitability of half-bred ewes, bred at Rothamsted by using a Scotch half-bred ram on the best of our commercial Scotch half-bred ewes. An attempt will be made to breed from some of the ewe-lambs.

(2) Comparison of a first-cross between a Cheviot ewe and a Dorset Horn ram with the Scotch half-bred. Six ewe hoggs of this Dorset Horn cross have been purchased from the Earl of Elgin ; these are, as far as is known, the only ones at present in the country. If they are as satisfactory as the half-bred, and in addition can take the ram over a wider period of time, they may become attractive commercially. The Dorset Horn is also being tried on the Scotch half-bred ewe, although this is a second cross.

(3) Examination of the possibilities of breeding from ewe lambs. Many farmers do this successfully, but the average type of ewe lamb which we have purchased during the past two years has been too young and small, and the result has been unsatisfactory. We are now trying bigger and more expensive half-bred ewe lambs at Woburn with results which, at present, are more promising.

In October, 1930, the flock consisted of 98 half-bred ewes, 97 gimmers and ewe lambs and 300 lambs. All the ewes were put to the Suffolk ram. Lambing began on March 10th and extended till April 14th ; the number of lambs on May 30th was 187, consisting of 2 triplets, 62 doubles and 57 singles.

Cattle. In October, 1930, the stock consisted of four in-calf Shorthorn heifers and 23 cross-bred Angus stores. During the year polled black calves were purchased locally from dairy farmers (Polled Angus bull and Shorthorn cow), and two more heifers ; there were born also six calves. The four heifers during their lactation period reared 35 calves between them.

This method gives us well-reared animals in sufficient number to stock our grass land adequately, and at less cost than the purchase of store cattle in spring. It is capable of considerable development, and we hope that the services of a recorder may become available so as to help in working out the various problems connected therewith.

Pigs. In October, 1930, the herd consisted of 21 Wessex Saddleback sows, one large white boar and one Wessex boar ; no fresh sows have been purchased, but 8 have been brought into the herd from our own litters. By far the greatest number of the pigs have been crosses, sold as stores soon after weaning (some 12 weeks old) or for pork when about five months old and weighing from 80 to 110 lb. dead weight.

Buildings. The building developments outlined in the previous Report have now been completed, although the equipment, both mechanical and electrical, is not yet complete, through lack of funds.

E

Implements. The following firms have lent us implements in addition to those mentioned in the 1930 Report:

Austin Motor Co. (tractor).

Miller Wheels, Ltd. (Patent Tractor Wheels).

R. A. Lister & Co. (power-driven sheep-shearing machine).

We have also been indebted to Messrs. Massey-Harris, Ltd., for the loan for a few weeks of a four-wheel-drive tractor, tractor-plough and cultivator.

Staff. C. Frith left us in July, 1931, and went as assistant to a farmer in Cambridgeshire, who is adapting his system to mechanisation. J. R. Moffat came in December, 1931, as voluntary assistant, and is occupied with our sheep investigations and with our various farm records.

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.

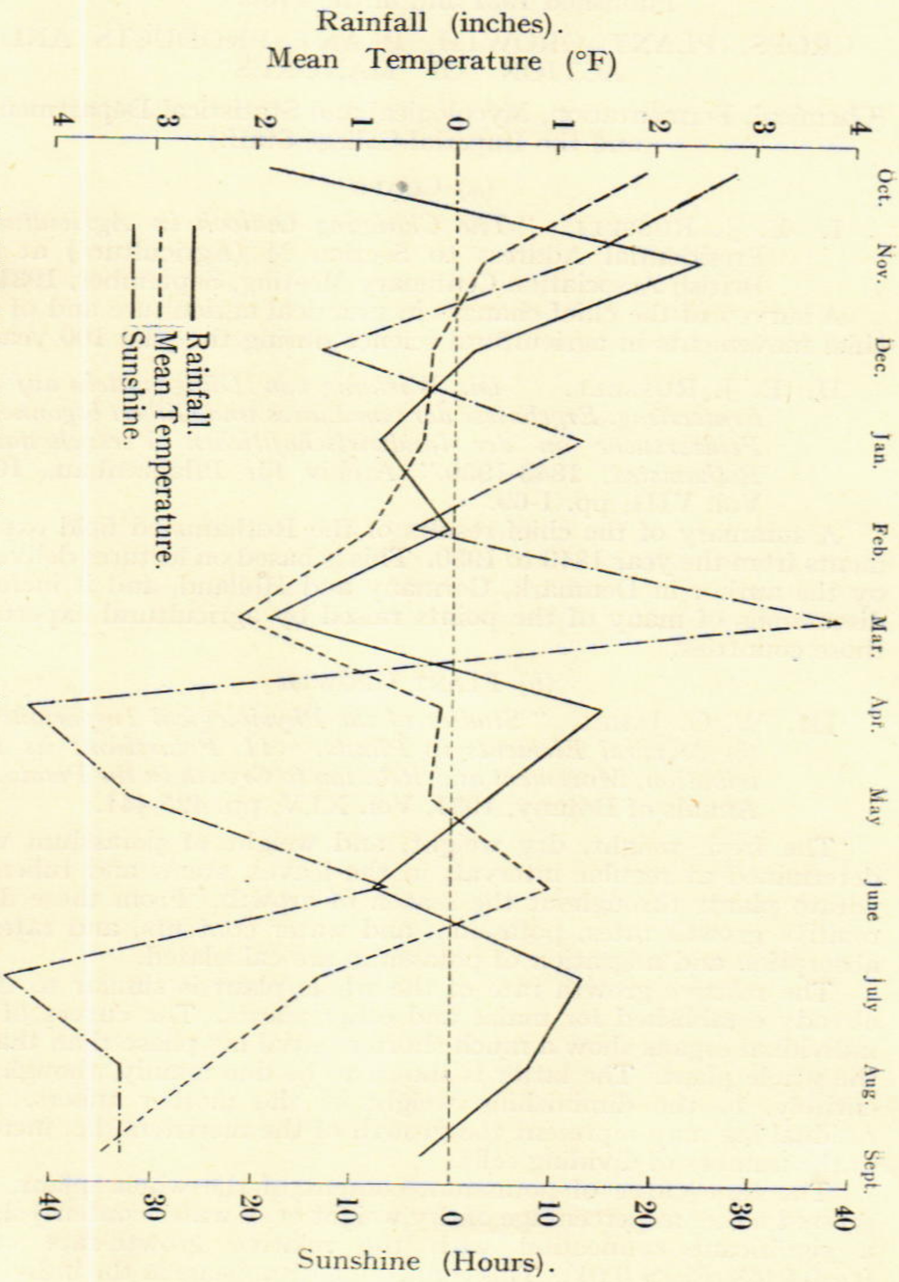
Additional data are collected under the following heads:

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.

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 complete 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 making single temperature measurement for use in calculating averages.



Deviation from average monthly values of sunshine, mean air temperature, and rainfall. Season 1930-31.