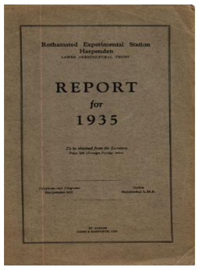
ROTHAMSTED RESEARCH

Report for 1935



Rothamsted Report for 1935

Rothamsted Research

Rothamsted Research (1936) *Rothamsted Report for 1935 ;* Report For 1935, pp 20 - 96 **- DOI: https://doi.org/10.23637/ERADOC-1-67**

REPORT FOR 1935

The purpose of the Rothamsted investigations is to develop a science of agriculture that farmers, manufacturers, merchants, expert advisors, lecturers and others can use in their daily work. The range of the investigations includes the growth and composition of crops, the properties of soils, of fertilisers and manures, the conditions in which each can be used to the best advantage, soil management, plant diseases, insect pests, bees and other subjects. Every effort is made to ensure that the information obtained is trustworthy and to specify the conditions over which the results may be expected to hold good.

It is recognised that British agriculture is exceedingly complex, owing to the wide variations in soil and climate in these islands; and further that its economic position is liable to constant change owing to the peculiar relation in which the country stands to the towns. Only about 10 per cent. of our population is concerned in agriculture, yet this small body of people produces about 40 per cent. of the food of the entire nation, omitting such things as tea, oranges, etc., which cannot be grown here. No other body of farmers has a better record than this. Whether one judges by value of agricultural output per acre or value per man the achievement of British farmers is remarkably good.

The importance of a prosperous agriculture is widely recognised, and various devices are now adopted to ensure that the British farmer shall have a fair share of the home market. But this puts upon him the responsibility of maintaining a high standard of efficiency, and to this end it is imperative that he should have at his disposal reliable information about the materials and methods he uses, and that he should know of alternatives that he can adopt whenever he sees some reason for making a change. A method advantageous for one farmer may be quite unsuited for his neighbour, but all alike benefit from the knowledge yielded by properly conducted experiments. Our purpose is to obtain this knowledge and to put it into such form that it can be utilised by all who are interested.

This view of our function accords with the historic development of Rothamsted. Lawes himself declared, on the occasion of the opening of the Testimonial Laboratory in 1855, that "the object of these investigations is not exactly to put money into my pocket, but to give you the knowledge by which you may be able to put money into yours."

This is also the most economical procedure. Agricultural experiments are necessarily slow, each one usually taking several seasons to complete, while economic changes march quickly and *ad hoc* experiments may easily give their information too late to be of much importance. On the other hand, sound trustworthy knowledge about soils, crops, fertilisers, etc., has permanent value and can be used for the most diverse purposes. The agricultural crisis of recent years has by common consent been the worst in our history, yet farmers did not suffer as much as in some of the earlier ones. There can be little doubt that one important reason lay in the better research, educational and advisory services now available.

THE WORK OF 1935.

During the season 1935 much steady progress has been made in all departments of the Station, and some of the old work has reached a definite stage where it could be regarded as sufficiently advanced for final publication and a new direction could be given to the programme. The examination of the 50 years' experimental work at Woburn (1877-1926) has been completed, and the book is now being published by Messrs. Longmans as one of the Rothamsted Monographs on Agricultural Science. Mr. Cutler and Miss Crump have rounded off a great deal of their work, and published it also as a Rothamsted monograph, " Problems in Soil Microbiology." In both cases time and resources have been set free for new lines of investigation. Mr. Samuel has completed his survey of mycological problems and drawn up a programme, on which a start has been made.

CROP PRODUCTION

During the past few years many experiments have been made to investigate the response of the more important crops to fertilisers. The results have been disseminated among farmers, fertiliser manufacturers, agricultural experts and others interested and have influenced fertiliser recipes and practice enabling farmers to obtain better crops at little if any more cost and often at less. When one recalls the fact that some £6,000,000 was spent by farmers on fertilisers in 1934-5, according to the reports of the various fertiliser associations, it is evident that a saving of a few per cent. in the efficiency of utilisation amounts to a very respectable total.

The experiments show, however, that on our present methods the farmer recovers only a part of the fertiliser used. Of the nitrogen applied, even in the most efficient fertilisers, not more than 40 to 60 per cent. is recovered, and the lower figure is more usual than the higher. Recovery of phosphate is smaller and rarely exceeds 25 per cent. even on grassland, and after residual effects have been taken into consideration. Numerous experiments are now being made to explore the possibility of a better utilisation of the fertiliser, and in the recent experiments on sugar beet and potatoes the fertiliser tests are usually combined with cultivation tests such as time of sowing, width of spacing, method of placing manure, etc. A number of these experiments are made not only at Rothamsted and Woburn, but at outside centres also, and they are rendered the more important because so far the sugar beet crop commonly fails to respond adequately to the fertilisers used, though for what reason is not yet clear. These outside experiments are much appreciated by farmers: in the Isle of Ely, for instance, the Branch of the National Farmers' Union asked us to support their application to the County Council for a County Agricultural Organiser in order that this type of work might be developed.

GRASSLAND EXPERIMENTS

As in previous years, a number of grassland experiments have been carried out in different parts of the country to compare the values of the different types of basic slag now available or likely to become so, and also to study the effects of an even cheaper material, mineral phosphate. These experiments are carried out under the ægis of the Ministry of Agriculture Basic Slag Committee, and at the request of the slag makers and largely at their expense; they are being continued and extended to include certain new types of slag resulting from changes in the method of steel making. The result has been to prove the general superiority of high soluble basic slag over other forms, although the low soluble slag and the mineral phosphate both have value in certain conditions which are gradually being discovered. Already these investigations have had the very useful result of increasing the proportion of the agriculturally effective slags as against those of less agricultural value: this is shown by the following figures of deliveries of ground basic slag in Great Britain :—

	Deliveries, Tons			Percentage of Total Deliveries	
	High Soluble (80% or more)	Low Soluble	Total	High Soluble (80% or more)	Low Soluble
1924-1925 ..	126,025	117,514	243,539	51.8	48.2
1929-1930 ..	222,342	83,407	305,749	72.7	27.3
1934-1935 ..	203,070	77,353	280,423	72.4	27.6

The new medium soluble slags, however, present special difficulties in that they show greater differences in effect than can be accounted for by their solubility in citric acid. With the taking over of a considerable area of additional grassland in 1934, it has become possible to arrange for grassland experiments to be made at Rothamsted also, and plans for these are being worked out. An investigation is being undertaken at the request of the Royal Agricultural Society to ascertain the effect on grassland of feeding cake to the animals grazing there: in particular to discover how far any improvement effected can be related to the composition of the cake and how long such improvement lasts. Unfortunately it has not yet been found possible to design a completely satisfactory grazing experiment: the older types of experiment do not satisfy modern statistical tests. An attempt is being made this year to overcome the difficulty by fencing off small areas within the grazed plots for short periods and weighing and analysing the herbage produced.

ARABLE CROPS.

SUGAR BEET. These experiments are carried out under the ægis of the Sugar Beet Research and Education Committee of the Sugar Beet factories and the Ministry of Agriculture.

Spacing Distance. During the past three years the effects of 10-, 15- and 20-inch spacings have been tested. The results have varied with the season, but on the average of the three years no marked effects have been produced by differences in spacing.

Effect of Spacing: yields of washed roots; tons per acre.

	Rothamsted				Woburn			
	1933	1934	1935	Mean	1933	1934	1935	Mean
20-in. rows ..	5.5	14.5	11.4	10.5	8.5	18.3	11.9	12.9
15-in. rows ..	6.5	13.7	10.7	10.3	9.0	19.2	12.9	13.7
10-in. rows ..	7.6	13.9	11.1	10.9	10.2	17.9	13.0	13.7

In 1933 the yields at both centres increased steadily as the spacing narrowed; but not in the later years. The yields in 1933 were poor, and the beet remained small however wide the spacing, so that a higher plant number meant a higher yield. In 1933, narrower spacing increased the sugar percentage, but it was without effect in 1934 and 1935 and on the average it was not worth the additional hand labour required. The spacings in the factory series of sugar beet experiments vary from 18 to 22 inches.

Effect of sulphate of ammonia at different spacings. Sulphate of ammonia had no effect on yield at Rothamsted in 1933, but in both later years its effects were greatest at the narrowest spacing. At Woburn there were significant responses to sulphate of ammonia in 1933 and 1935; in 1933 the response increased as the spacing narrowed, but not in 1935, and on the average there was little difference between the three spacings, the 15-inch spacing giving the highest mean response.

Responses to sulphate of ammonia (3 *cwt. per acre*) *at different spacings.*
Washed roots (tons per acre)

	Rothamsted				Woburn			
Spacing	1933	1934	1935	Mean	1933	1934	1935	Mean
20-in.	−0.15	1.72	1.25	0.94	0.83	0.06	1.15	0.68
15-in.	0.36	0.78	2.22	1.12	2.91	−0.72	1.83	1.34
10-in.	0.09	2.32	2.83	1.75	2.94	−0.48	0.31	0.92
Mean	0.10	1.61	2.10	1.27	2.23	−0.38	1.10	0.98

There are indications that sulphate of ammonia had less harmful effect on sugar percentage at the narrower spacings, but the effect was small and not significant. The mean yields of total sugar, in cwt. per acre for the three years 1933, 1934 and 1935, were:

	Sulphate of ammonia per acre	20-in.	15-in.	10-in.
Rothamsted ..	None	33.4	32.6	33.8
	3 cwt.	35.8	35.8	39.0
Woburn	None	42.6	44.1	44.7
	3 cwt.	43.1	47.6	47.3

At Rothamsted there is little difference between the mean yields with the 20- and 15-inch spacings, whether nitrogen was applied or not; with the 10-inch spacing, however, the application of nitrogen gave an increased response of about 3 cwt. of sugar. At Woburn the results for the 15- and 10-inch spacings are similar and show an increased yield over the wide spacing of 2 cwt. in the absence of nitrogen and $4\frac{1}{2}$ cwt. in the presence of nitrogen. The indications at both centres are, as might be expected, that nitrogen produces a greater effect at narrower spacings.

Bolters. In the Rothamsted experiment of 1935 about 18 per cent. of the plants sown at the earliest date (March 15) bolted. In three of the experiments at Bardney and Brigg the proportion was about 5 per cent. and in one it was less than 1 per cent. At one centre about 25 per cent. bolted and an experiment was made involving four treatments : (1) untreated, (2) woody bolters pulled, (3) woody bolters pulled, other bolters cut in July, (4) all bolters cut in July. Some of the plants cut in July did not again bolt. The average weights per root were :

	Good beet	Woody bolters	Non-woody bolters	Cut and not bolted
Average weight per root (lb.) ..	1.28	0.79	1.30	1.18
Sugar, per cent. ..	17.71	17.02	17.11	17.23

The chief loss from bolters is that the woody ones weigh about 40 per cent. less per root than the others, although in all bolters the sugar percentage is slightly reduced. Since about 60 per cent. of the bolters were woody the loss of sugar on all bolters averaged about 25 per cent. and on the whole crop was about 6 per cent. This was much smaller than the rather alarming appearance of the bolters on the field had suggested. This estimate takes no account of the effect which the bolters might have on the growth of neighbouring plants which did not bolt.

At Rothamsted, where most of the bolters were woody, the results were :

	Good beet	Bolters
Average weight per root (lb.)	0.61	0.48
Sugar, per cent.	16.49	16.15

As before the average loss in sugar per bolter is about one quarter.

The cutting of the bolters in July proved very successful, giving an increase of 3 cwt. per acre in total sugar.

The standard fertilisers affected the percentage of bolters as follows :

Percentage of bolters

	Sulphate of ammonia			Superphosphate			Sulphate of potash		
	None	One dose	Two doses	None	One dose	Two doses	None	One dose	Two doses
Caistor ..	2.9	4.7	6.1	4.2	4.8	4.9	4.2	4.9	4.9
Scotton	1.4	2.8	3.4	2.2	2.8	2.8	2.4	2.7	2.6
Metheringham	4.7	5.7	7.3	4.8	6.4	6.5	5.0	6.4	6.3
Rothamsted	13.0	20.0	22.3						

All three fertilisers increased the percentage of bolters, the increase being greatest for sulphate of ammonia, which had also the greatest effect on yield. For potash and phosphate the single and double dressings behaved alike, whereas sulphate of ammonia gave a more uniform increase. However, the effect is unimportant and is well covered by the increases in yield given by the sulphate of ammonia at all four centres.

The amount of bolting at Rothamsted was also affected by the width between the rows, decreasing as the spacing narrowed.

	Spacing. 20 in.	15 in.	10 in.
Percentage of bolters	22.3	18.1	14.9

Effect of Fertilisers on Yield.

The Staffs of the Sugar Beet factories generously co-operated in an extensive series of manurial experiments and we wish to record our deep indebtedness to them for their help. An elaborate series of chemical examinations of the various soils is being carried out and is already yielding most valuable information about the relations between soil properties and fertiliser responses. The average yields for all the factory experiments of **1935** were :

	Sulphate of Ammonia.			Super-phosphate.			Muriate of Potash.		
Cwt. per acre ..	0	2	4	0	3	6	0	$1\frac{1}{4}$	$2\frac{1}{2}$
Roots, tons per acre	8.94	9.58	10.07	9.46	9.55	9.58	9.43	9.59	9.58
Tops, tons per acre	6.86	8.12	9.42	8.03	8.17	8.20	8.12	8.18	8.10
Sugar, per cent ..	17.22	16.99	16.59	16.95	16.91	16.95	16.80	16.96	17.04
Sugar, cwt. per acre	30.8	32.7	33.5	32.2	32.3	32.6	31.8	32.6	32.7
Purity, per cent. ..	88.2	88.1	87.5	87.9	87.9	88.0	87.8	87.8	88.0

Mean Yield per acre. Washed Roots. tons.	Sugar. cwt.	Increase in sugar in cwt. per acre for 4 cwt. sulphate of ammonia.	6 cwt. super-phosphate.	$2\frac{1}{2}$ cwt. Muriate of potash.
9.53	32.4	+2.7	+0.4	+0.9

Heart-rot in Sugar Beet.

For the first time at Rothamsted a severe attack of "heart-rot" in sugar beet was found on the plots of the spacing, sowing-date, nitrogen experiment (*see* p. 23). The disease was rather localised in its occurrence. One block of the experiment was much more seriously affected than the rest, and beet in other parts of the same field were practically free from the disease. The percentage of plants showing symptoms decreased with later sowing. The disease is attributed to boron deficiency and is being further studied.

Potatoes. At Rothamsted the effect of time of application of the fertilisers was studied, the dung being either ploughed in during November or applied in the bouts in spring, and the artificials either broadcast before ridging up or applied in the ridges. In each case application in the bouts proved the better. The mean yields were, in tons per acre :

	Fertiliser Applied. Before bouting.	In the bouts.
Dung	7.15	8.06
Complete artificials	7.58	9.70

The increases due to dung were 3.4 tons per acre where no superphosphate or muriate of potash were given and 1.3 tons per acre where they were present. Sulphate of ammonia applied alone had no effect, but with minerals or dung it gave an increase of 2.1 tons per acre.

The effects of treatments on the percentage of ware were similar to those on yield.

The potatoes were lifted in October, and the produce stored in a clamp in the usual way until February, the produce of the different plots being kept distinct. The loss in weight averaged 4.5 per cent. It was less for dung in the bouts (4 per cent.) than for dung ploughed in (6 per cent.).

About 7 per cent. of the potatoes went bad on storing. Dung and minerals both increased the proportion of bad potatoes by 2 per cent. ; sulphate of ammonia had little effect. Further, the potatoes did not keep so well when dung was applied in the bouts as when it was ploughed in, the loss being 8.7 per cent. against 6.3 per cent. On the other hand, artificials applied in the bouts gave in this experiment better keeping potatoes than artificials broadcast before bouting.

Percentage ware. In view of the regulations of the Potato Marketing Board it is now important to study the effects of fertilisers on the proportion of ware as well as on total yields. The numbers of experiments used in the following summary are 3 in 1932, 6 in 1933, 13 in 1934 and 8 in 1935. The amounts of manures were fairly uniform and the results have been reduced to fixed amounts of fertiliser. The size of riddle was generally $1\frac{1}{2}$ to $1\frac{3}{4}$ inches. The average percentage of ware varied, with one exception, from 60 per cent. to nearly 100 per cent.

The mean increases in percentage ware given by sulphate of ammonia (3 cwt. per acre), superphosphate ($3\frac{1}{2}$ cwt. per acre), sulphate or muriate of potash (2 cwt. per acre) and poultry manure (about 1 ton per acre)were :—

	Centres with significant yield response	Other centres.
Sulphate of ammonia	1.65 (20)	−0.36 (10)
Poultry Manure	1.43 (9)	−1.82 (4)
Superphosphate	0.81 (7)	−1.16 (12)
Sulphate or muriate of potash	10.46 (7)	0.82 (8)

The figures in brackets show the numbers of experiments over which the means are taken.

The fertilisers increased the percentage ware only where they also increased yield. Where there was an increase in yield, potash consistently increased the percentage ware, giving a striking average increase of 10 per cent. The other three fertilisers had smaller and less consistent effects. There was a large proportion of very small responses for all fertilisers, but these mostly occurred at centres where the mean percentage ware was over 90 per cent. and little further increase was possible.

Four experiments included farmyard manure ; all gave a clear response in yield and two gave a large increase in percentage of ware :—

	Mean per cent. ware	Increase in per cent. ware with farmyard manure
Rothamsted 1932 (15 tons)	93.5	0.5
,, 1934 (20 tons)	87.2	1.2
,, 1935 (15 tons)	70.8	17.7
Wimblington 1935 (8½ tons)	73.3	16.6

Outside Centres. The manurial experiments on potatoes were made as usual at a number of centres, which may be conveniently grouped as fenland and as mineral soils.

Fenland Soils.

Yield, Tons per acre, Total Crop, 1935.

Centre.	Standard Error.	Sulphate of Ammonia.			Super-phosphate.			Sulphate of Potash.		
			cwt.	cwt.		cwt.	cwt.		cwt.	cwt.
		0	1½	3	0	4½	9	0	1½	3
Light peaty soils										
Thorney ..	±0.466	7.98	9.00	8.23	8.05	8.16	9.00	7.86	8.50	8.85
Mepal ..	±0.414	8.81	9.54	10.12	8.91	9.57	9.99	7.16	9.84	11.47
Wimblington	±0.143	6.66	—	7.61[1]	6.90	7.38[1]	—	6.54	—	7.74[1]
Heavy Fen soils										
March ..	±0.314	5.23	7.04	8.13	6.15	6.93	7.32	6.71	7.18	6.51
Little Downham	±0.194	3.50	5.03[2]	6.53[2]	3.91	5.34	5.81	4.73	5.29[3]	5.03[3]

(1) Sulphate of ammonia 2½ cwt. ; Superphosphate 6 cwt. ; Sulphate of potash 2½ cwt.
(2) Sulphate of ammonia 2½ and 5 cwt.
(3) Sulphate of potash 1 and 2 cwt.

At Thorney responses were not very marked, but at Mepal nitrogen and especially potash acted well, the increase for the 3 cwt. of sulphate of potash being 4.3 tons per acre. At Wimblington all three fertilisers gave a significant increase. Dung proved very effective ; 8½ tons of dung gave an increase of 3.70 tons in absence of potash and 1.24 tons when potash was present, this interaction being significant.

On the heavy soils nitrogen and phosphate did well, but there was no response to potash. The experiment at Little Downham was planted with early potatoes, but they were cut down by the great frost of 17th May and allowed to stand later than usual. They yielded well and responded markedly to fertilisers.

Mineral Soils

The experiments on mineral soils fall into two groups, one testing the effects of the separate fertilisers, as above, the other showing the action of increasing levels of a mixed fertiliser.

https://doi.org/10.23637/ERADOC-1-67

Yield, tons per acre, total crop, 1935

Centre.	Standard Error. tons.	Sulphate of Ammonia. None	S'gle	D'ble	Super-phosphate. None	S'gle	D'ble	Sulphate of Potash. None	S'gle	D'ble
Deep silt.										
Wisbech ..	±0.346	10.38	10.67[1]	10.76	10.22	11.02[1]	10.56	10.42	11.12[1]	10.28
Light loam.										
Midland College	±0.279	8.64	8.37[2]	8.61	—	—	—	8.60	8.24[2]	8.79
Warp.										
Owston Ferry Lincs.	±0.396	—	—	—	—	—	—	9.14	10.54[3]	10.97
Heavy.										
Cadishead, Lancs. ..	±0.403	—	—	—	3.63	4.88[4]	—	—	—	—

(1) Single sulphate of ammonia 2 cwt.; single superphosphate 4 cwt.; single sulphate of potash 2 cwt.
(2) Single sulphate of ammonia 1½ cwt.; single sulphate of potash 1½ cwt.
(3) Single sulphate of potash 1 cwt.
(4) Single superphosphate 5 cwt.

There was a response to potash at the warp land centre at Owston Ferry even in presence of dung, and to phosphate on the heavy soil at Cadishead. At the other two centres the usual dressing of dung produced maximum yields.

Yield, tons per acre, total crop, 1935
Increasing levels of complete Fertiliser.

	Fertiliser cwt. per acre. 0	4	8	12	16	Standard Error.
Light loam.						
Midland College, Notts.	7.83	8.02	7.79	7.94	—	±0.355
Sandy.						
Messingham, Lincs. ..	5.26	6.88	8.70	9.74	9.81	±0.379
Limestone						
Grayingham, Lincs. ..	8.47	9.03	9.33	9.31	9.64	±0.396

Dung was given at all centres. At Messingham there was a good response, but a significant falling off in effectiveness at the higher levels of manuring. At Grayingham the response though small was significant and proportional to the dressing applied.

Beans. In 1934, the effects of dung, nitrochalk and muriate of potash on the yield of beans were studied, and in 1935, superphosphate was included and two spacings of the rows were tried. The mean yields were :—

	Mean Yield cwt. per acre.	Increase due to: Dung. 10 tons per acre.	Nitro-chalk 0.4 cwt. Nitrogen per acre.	Super-phosphate 0.6 cwt. P_2O_5 per acre.	Muriate of Potash 1.0 cwt. K_2O per acre.
1934 Grain	18.7	*2.3*	0.6	—	1.6
Straw	15.0	*2.1*	0.6	—	1.0
1935 Grain	21.0	*5.6*	1.2	−2.0	*2.7*
Straw	26.3	*9.8*	2.4	−1.7	2.8

Significant increases are printed in italics

The mean yields and the effects of fertilisers were greater in 1935 than in 1934. Dung gave large increases in both years but especially in 1935. Nitrochalk gave slight but not significant increases : superphosphate had no effect, the apparent depression in 1935 not being significant. Muriate of potash apparently increased the yield in both years ; the effect for grain in 1935 was significant, and that for straw almost so. The result is interesting for, apart from potatoes, most crops on the heavy Rothamsted soil are not very responsive to potash.

The 18 inch spacing of the rows gave an increased yield over the 24 inch spacing of 2.8 cwt. per acre in grain and 4.6 cwt. per acre in straw. The response to muriate of potash was significantly greater for the wide than for the narrow spacing and there was an indication of a similar effect for dung. This result was unexpected, for with narrow spacing individual plants have a more restricted nutrient supply than with wide spacing, and might be expected, therefore, to show greater responses to added fertilisers as indeed the sugar beet did. (p. 23.)

WHEAT. The question when best to apply nitrogenous fertiliser to wheat has been much studied. Very variable results have been obtained, the effect of the nitrogen depending largely on the weather. Excessive rainfall may wash the nitrogen beyond the range of the plant roots, while lack of rain may so limit growth that additional nitrogen, even if taken up by the plant, could not be utilised.

The influence of variable water-supply can be eliminated in pot-culture, and in these conditions Dr. Watson found that nitrate of soda gave the same increase of grain yield at whatever time it was applied from sowing time to the end of May. A still later application, after ear emergence in June, had no effect on yield, although the nitrogen was as fully taken up as before. The yield of straw, however, fell off steadily with later application, but the grain was larger and of higher nitrogen content than for early application. This suggests that application towards the end of May is likely to be most efficient, since the yield of grain is the same as for early application, while the quality is better and the increase of the straw, and consequently the potentiality for lodging, is less.

The results of field experiments at Rothamsted and Woburn are consistent with this view. From 1926 to 1931 seven complex experiments were carried out at Rothamsted, in which early and late dressings of sulphate and muriate of ammonia were applied. The average responses were :—

Increase produced by 0.2 cwt. N. per acre. Mean of sulphate and muriate of ammonia, Rothamsted.

	Applied early (March)*	Applied late (May)*	S.E.
Grain } cwt. per acre	1.12	0.81	±0.23
Straw } cwt. per acre	3.63	2.76	±0.27

* Except for one "early" application on April 11th, and one "late" application on June 5th.

The difference was not significant for grain, but it was for straw, late application giving significantly less increase than early application.

A second series of experiments was begun in 1934, at Rothamsted and Woburn, in which a wider range of times of application was tested. In 1934 no significant increases were obtained: at Rothamsted, the yield without nitrogen was already very high (35 cwt. grain per acre); and at Woburn the standard error was abnormally large, though a fall in straw yield with later application was suggested. In 1935, January application gave the greatest straw yield at Rothamsted and Woburn. For later applications the increase in straw yield fell steadily, as in the other experiments. The inferiority of seed-bed application compared with the spring dressings is in agreement with the Broadbalk results.

In 1935 nitrogenous fertilisers again gave no significant increase in grain yield at Rothamsted. On the other hand, at Woburn, there was a significant response, though as in the pot experiment, the time of application caused no difference in the result.

Wheat is commonly grown at that stage in a rotation when the fertility of the soil is at its highest. The comparatively small increase of grain yield in the 1926-1931 series of experiments at Rothamsted, and the absence of any response in 1934 and 1935, raises the question whether nitrogenous fertiliser is necessary for wheat on land in good heart.

Early spring applications of nitrogen frequently produce spectacular increases in the thickness, height and colour of the wheat in May, when tillering is at its maximum and elongation of the shoots is beginning, while the effect of later dressings is much less obvious. This was shown by counts of shoots and measurements of height at Woburn in 1934 and 1935. But these marked differences were not accompanied by corresponding increases in grain yield. The popularity of early dressings may be partly due to this obvious effect on spring growth. A lush early growth, however, may mean only a heavier straw crop and difficulties at harvest due to lodging, with no advantage in extra grain yield.

This does not apply, however, to systems of farming involving frequent corn crops, with little dung and where wheat does not follow a ley, a leguminous crop or a fallow.

Malting Barley

In the autumn of 1934 and again in 1935 conferences were held at Rothamsted on the growing of malting barley. They took the form of an exhibition of barley samples sent in by farmers from all parts of the country, and valued by the Barley Valuation Committee of the Institute of Brewing.

In both seasons the summers were dry and the harvesting conditions very good. In 1935, however, the spring was much colder and wetter than in 1934, and growth started in a moister soil. The rainfall at Rothamsted was :—

	1933-34	1934-35
October to May inclusive, inches	11.64	19.94

On May 17th, 1935, a severe late frost caught some of the autumn sown barleys in the early stages of ear formation. After a wet and cheerless early June the weather turned drier than in 1934 and most of the growers had practically no rain from mid-June till after harvest, though some had showers in mid-August.

The grading of the samples was as follows :—

	1934		1935	
	No.	per cent.	No.	per cent.
Grade I	6	3.2	2	0.7
Grade II	4	2.1	12	4.4
Grade III	13	6.9	37	13.7
Grade IV	22	11.6	58	21.5
Grade V	52	27.5	83	30.8
Grade VI	65	34.4	60	22.2
Grade VII (grinding)	27	14.3	18	6.7
Total	189	100.0	270	100.0

Each stage in grading represents about 5/- per quarter in value. Most of the samples fall into Grades V and VI, and very few reached the top grades of high quality. As observed before, the nitrogen content of the grain was related to the grading for a particular variety : for the Norfolk Spratt Archer of 1935 the values were :

Grades	I	II	III	IV	V	VI	VII
Per cent. Nitrogen in dry grain	1.28	1.33	1.41	1.42	1.45	1.53	1.53

An examination of the varieties sown gave the following results:

Number of samples of Barley 1934 *and* 1935.

	Plumage-Archer.	Spratt-Archer.	New Cross.	Plumage.	Other varieties.
Kent	17	—	—	—	—
Essex	20	10	—	—	5
Norfolk ..	11	85	11	1	7
Suffolk	7	16	3	—	4
Lincolnshire ..	6	18	14	2	3
Yorkshire ..	6	2	—	15	3
Somerset ..	12	11	7	1	1
All Counties ..	133	199	44	27	52

Kent and Essex sent mostly Plumage-Archer : Norfolk sent Spratt-Archer : Plumage was received in any quantity only from Yorkshire. Spratt-Archer and Plumage-Archer together accounted for almost three quarters of the samples.

Most of the samples came from medium and light soils : few from heavy soils : one third were from soils on or close to chalk, limestone, oolite, or stone brash.

	Number of soils, both years.			
	Heavy.	Medium.	Light.	Total.
Calcareous	9	85	52	146
Not calcareous	90	81	115	286
Total	99	166	167	432
Per cent. of Total.				
Calcareous	2	20	12	34
Not calcareous	21	18	27	66
	23	38	39	100

About 14 per cent. of the samples in each season were autumn sown, and these usually graded better than the spring sown barleys. Thus for the two years :

In grades I, II, and III.	35 per cent. were autumn sown.
In grades IV, V.	12 per cent. ,, ,, ,,
In grades VI, VII.	8 per cent. ,, ,, ,,

Certain districts favoured autumn sowing much more than others, for example, in 1934, nearly half the barleys from Essex had been autumn sown and in 1935 nearly three-quarters.

In Norfolk barley now commonly follows sugar beet instead of swedes and turnips. Elsewhere, however, it still often follows turnips. Apparently it rarely follows potatoes.

Preceding Crops.

Barley after	1934 All counties.	1935 Norfolk.	1935 Others.	1935 All counties.	Both years total.
Cereals . .	90	22	69	91	181
Beet and Mangolds . .	38	58	39	97	135
Swedes, turnips, kale . .	19	10	30	40	59
Clover, peas, etc.	15	5	10	15	30
Potatoes . .	2	—	3	3	5
Bare and half fallow . .	3	—	1	1	4
Other crops . .	1	2	6	8	9

Much information was obtained in regard to the manuring of the barley. It is no longer a starvation crop. The experiments made by Rothamsted under the Institute of Brewing Research scheme during the last ten years showed clearly the advantage of suitable manuring when care was taken not to lodge the crop. This result has clearly passed into practice. Of the 270 samples sent in in 1935, 159 had received manure, 124 had received nitrogenous fertiliser, and no less than 61 of these had followed beet, turnips, or some other crop receiving dung, showing that the growers were prepared to give nitrogen even on land already in good condition. Some 51 crops had received compound fertilisers, which in 21 cases were the new high grade materials containing ammonium phosphate ; but many growers preferred to make their own mixtures.

EXPERIMENTS ON VEGETABLE CROPS

The importance of vegetable crops has considerably increased during recent years. Thus, for certain of the more important crops, the acreage returns for 1922 and 1934 are as follows :

Crop.	Acreage. 1922	1934	Increase per cent.
Carrots	14084	16432	+16
Onions	3557	2099	−59
Cabbage	27954	36981	+32
Brussels Sprouts	14951	34048	+128
Cauliflowers and Broccoli ..	10475	20107	+92
Celery	5282	7510	+42
Rhubarb	5718	8233	+44
Green beans	12907	16833	+30
Green peas	50894	74363	+45

Thus, with the exception of onions, there has been a substantial increase in the acreage planted with vegetables in recent years. The value per acre of the vegetable crops is also high; the actual prices realised depend greatly on quality, supplies, and the effect of weather on demand.

An estimate of the annual supplies and values of vegetables for human consumption has recently been made* from which may be derived the following data relating to the years 1930-32:

Crop.	Av. Yield per acre, tons.	Gross Value† per acre, £
Outdoor Cabbage lettuce	8	75
Celery	10	60
Broccoli and Cauliflower ..	8	71
Spring Cabbage and Cabbage Greens	7	51
Autumn Cabbage	9	40
Sprouts	3.7	53
Green Peas	2.2	30
Ripe Onions	7	39
Topped Carrots	11.7	50
Red Beet	12	48

† Freight and market charges to be deducted.

Prices also have been well maintained as compared with general farm produce, thus the agricultural index of all vegetables in 1934 was 143 (1911-13=100) whereas the general index of agricultural produce for the same year was 114.

The first experiments on vegetable crops conducted from Rothamsted, using the new technique, began in 1931, on winter cabbages, Brussels sprouts, and first early potatoes. There have now been put on record in the Station Reports some fifty experiments on vegetable crops carried out at Rothamsted, Woburn, outside centres, and by local workers operating general schemes of investigation administered from Rothamsted. The rapid expansion of this work was rendered possible by the investigation on the value of dried poultry manure put in hand by the Ministry of Agriculture and controlled from this station. It was decided to test this manure as

* "Min. Agric. Economic Series." No. 25, 1935. P. 172.

C

far as possible on market garden crops since its most promising outlet would probably be for small scale intensive cultivation.

Experience has shown that experiments with vegetable crops, although in most cases rather more exacting than with farm crops, offer no insuperable difficulties. As will be seen later, standard errors tend to be a little higher than the average of large scale root crops, but none the less a considerable number of statistically significant fertiliser effects will be found in the tables that follow. On the other hand certain crops have shown very small or even negative effects. Early potatoes, carrots, onions, strawberries have all been disappointing in this respect. The experiments are, however, only a first approach to a wide subject and many more will be required to obtain an adequate view of the fertiliser responses of vegetable crops.

More has been done with Brussels sprouts than with any other crop, so that the results of the experiments on the growth of this plant will be set out first. There are thirteen experiments with sprouts on record, but one at Rothamsted was practically a failure owing to damage by wood pigeons. Of the twelve good experiments, all show the effect of nitrogen as sulphate of ammonia usually at several rates of dressing, most of them test dried poultry manure and superphosphate and two test sulphate of potash. There are figures for the individual pickings, usually carried out on three occasions, but sometimes on four, and in most cases there are figures relating to the proportion of blown or unsaleable sprouts. The mean yields of total saleable sprouts and the increases for the various nutrients are set out in Table I. In this and succeeding Tables the single dressings of sulphate of ammonia (N_1) and dried poultry manure (M_1) were usually at the rate of 0.3-0.4 cwt. N per acre, the double dressings N_2 and M_2 being 0.6-0.8 cwt. N. Superphosphate (P) was at the rate of 0.4-0.6 cwt. P_2O_5 per acre ; while sulphate of potash K_1 was at the rate of 1.0 cwt. K_2O per acre, K_2 being 1.5-2.0 cwt. K_2O.

The mean yields ranged from 22.4 to 90.8 cwt. of saleable sprouts per acre with a general mean of 44.3 cwt. The most marked manurial effect was given by nitrogen. For the years 1933 and 1934 there are sufficient centres to make an estimate of the average effect of this nutrient in the form of sulphate of ammonia and poultry manure, the results being brought to a common basis of 0.6 cwt. N per acre. The figures are :—

Total Saleable Sprouts, cwt. per acre.

Mean increase for 0.6 cwt. N per acre.

	No. of Experiments	Sulphate of Ammonia.	Poultry Manure.
1933.. ..	6	+1.65	+2.74
1934.. ..	4	+12.95	+7.46

TABLE I.

Brussels Sprouts. Total saleable Sprouts, cwt. per acre.

Year.	Centre No.	Soil.	Mean Yield.	Increases for N_1	N_2	M_1	M_2	P	K_1	K_2	Standard Error.
1931	1	Light chalk ..	49.3	−2.4	−0.9	+5.8	—	—	—	—	±3.44
1933	2	Clay loam ..	29.8	−0.3(1)	−1.4(1)	—	+1.2	+2.2	—	—	±1.24
1933	3	Sandy ..	40.4	—	+9.0	—	+4.8	−1.9	—	—	±1.89
1933	4	Chalk loam ..	22.4	−3.0	−5.7	—	−1.7	—	—	—	±1.84
1933	5	Poor sand ..	24.7	+1.2	—	+0.4	—	+0.3	—	—	±1.44
1933	6	Boulder clay ..	40.3	—	+2.0	—	+8.2	+10.3	—	—	±1.09
1933	7	Medium-heavy	38.3	+1.1	—	—	—	−0.2	—	+9.7	±1.28
1934	8	Clay loam ..	90.8	+3.9	+10.2	+9.0	+8.2	—	—	—	±2.60
1934	9	Silty gravel ..	63.9	+11.6	+16.3	+4.4	+7.6	—	—	—	±1.53
1934	10	Gravel loam	43.2	+13.1	+20.9	+3.7	+8.2	—	—	—	±1.00
1934	11	Gravel loam	58.7	—	+10.2	—	—	−3.7	+1.6(2)	+4.2(2)	±2.10
1935	12	Silty loam ..	29.8	+3.9	+2.4	+3.2	+4.8	—	—	—	±2.95

(1) ±1.53. (2) ±2.56.

Responses were much greater in 1934 than in 1933, and in the more favourable season there is evidence that sulphate of ammonia was more effective than poultry manure providing the same amount of nitrogen. Thus at centres 9 (Wyboston, Bedfordshire), and 10 (St. Albans), the difference between sulphate of ammonia and poultry manure was significant.

The action of superphosphate was less general than that of nitrogen and only at one centre, No. 6 (Honeydon, Bedfordshire), on a boulder clay soil was its effect really important. In this experiment, however, 3 cwt. of superphosphate increased the yield by no less than 10.3 cwt., and it is probable that the superiority of poultry manure over sulphate of ammonia shown at this centre was due in part to the phosphate that the organic manure provided. There is some evidence of a beneficial effect of superphosphate on the heavy soil at centre 2 (Rothamsted).

Potash was tried at two centres only. At centre 7 (London Colney, Herts.) it gave the large increase of 9.7 cwt. for 3 cwt. of the fertiliser. In the following year at the same centre a smaller but nevertheless significant effect was obtained.

Earliness is a valuable feature in growing market garden crops and it is therefore important to trace the fertiliser effects through the successive pickings whose sum goes to make the total discussed above. The results are collected in Table II, which presents those centres at which the fertiliser responses were strongly defined. The total response in saleable sprouts is taken as 100 and the respective contributions of the separate pickings are expressed on this basis. The figures refer to the higher level of nutrient in each case.

TABLE II.

Saleable Sprouts.

Fertiliser responses in successive pickings.

Total response = 100.

Centre No.	Nitrogen. Pickings. 1st 2nd 3rd	Poultry Manure. Pickings. 1st 2nd 3rd 4th	Phosphate Pickings. 1st 2nd 3rd 4th	Potash Pickings. 1st 2nd 3rd 4th
1		+91 +31 −22		
2			+88 −19 +13 +18	
3	+77 +13 +10	+80 +14 +6		
6		+19 +35 +29 +17	+39 +34 +20 +7	
7				+28 +43 +20 +9
8	+ 8 +80 +12	−9 +97 +12		
9	+20 +58 +22	+30 +40 +30		
10	+82 +7 +11	+60 +30 +10		
11	+51 +33 +16			+196 −60 −36

In the above table there are 15 results showing three or more pickings. In nine instances the response in the first picking is the greatest, and in six of them over three-quarters of the total effect is to be found in the first picking. In the six experiments in which the first picking is not greatest the second picking is the largest. In no case is there more than 30 per cent. of the total response in the third picking, or 18 per cent. in the fourth. In several of the experiments the predominance of the fertiliser effect in the first picking is in itself significant, e.g., at centre **2** (Rothamsted) and **11**, (London Colney). The figures show that when a nutrient is effective, its action tends to be strongest in the early part of the season. Phosphate and potash both gave earlier crops at each of the two centres where they acted. Sulphate of ammonia and poultry manure, on the other hand, did not appear to hasten growth.

The experiments give some information on the relationship of fertiliser action and grade of produce for in most of them the weight of " blown " or unsaleable sprouts was ascertained, and in some of them the saleable sprouts were themselves graded. The effects of the nitrogenous manures on the weight of " blown " or unsaleable sprouts and their percentage of the total crop, including blown are given in Table III.

TABLE III.

Effects of nitrogenous manures on blown (or unsaleable) Sprouts expressed as increases over controls.

Centre No.	Increases cwt. per acre				Per cent. of total crop.			
	N_1	N_2	M_1	M_2	N_1	N_2	M_1	M_2
1	+3.0	+4.5	+6.5	—	+4.5	+5.5	+5.0	—
2	+0.2	+0.2	—	+1.1	+0.3	+1.3	—	+1.6
3	—	+2.1	—	+0.9	—	+1.6	—	+0.6
4	−0.5	−1.0	—	+0.5	−1.1	+2.7	—	+2.4
5	+2.0	—	+0.8	—	+4.3	—	+1.6	—
6	—	+1.2	—	+0.6	—	+1.5	—	−1.7
7	+0.5	—	—	—	+0.6	—	—	—
9	+1.1	+1.9	+1.3	+2.0	+1.0	+1.7	+1.6	+2.7
10	+0.8	+1.2	+0.2	+0.4	−1.7	−2.4	−0.7	−1.3

In eight of the nine experiments with sulphate of ammonia the actual weight of unsaleable sprouts per acre was increased, by an average of 1.4 cwt. per 3 cwt. sulphate of ammonia. The percentage of unsaleable produced was also increased in eight out of the nine experiments. At centre **10** (Oaklands), St. Albans, the effect of nitrogen on yield was so large that although the actual quantity of blown sprouts was increased, the percentage was smaller. Dried poultry manure behaved similarly to sulphate of ammonia at most centres. The effect of superphosphate was in general small, but at centre **6** (Honeydon, Bedfordshire), the unsaleable sprouts were increased by 1.6 cwt, while the percentage unsaleable was decreased by 0.6 per cent. In one experiment with potash the actual yield of unsaleable sprouts was increased by 1.3 cwt. but the percentage fell by 1.1. per cent. Taking the results as a whole, the effect of manures appears to be slightly to increase the actual weight of blown or unsaleable sprouts, but when the crop responds well to manures the final result is that the proportion of unsaleable produce is reduced.

Six experiments, set out in summary form in Table IV, are on record dealing with cabbages and Broccoli.

TABLE IV

Cabbages and Broccoli

Effect of Nitrogen, Phosphate and Potash

Weights or numbers per acre

Crop	Centre No.	Soil	Mean Yield Tons or Numbers	Increase for N_1	N_2	M_1	M_2	P_1	P_2	K†	Standard Error
Spring Cabbage	1	Light	13.6	+1.19	—	—	—	—	—	+0.43	±0.496
Spring Cabbage	2	Sandy	6.0	+1.17	+2.87	+0.65	+0.96	—	—	—	±0.838
Savoys	3	Medium	20.6	—	+7.42	—	+3.94	—	—	—	±1.270
Broccoli Heads	4	Shale loam	1.56	—	+0.22	—	+0.16[1]	−0.03	—	—	±0.097
Broccoli Outsides	4	Shale loam	7.28	—	+0.68	—	+0 48[2]	+0.02	—	—	±0.437
Number	4	Shale loam	5,838	—	+303	—	+100[3]	−49	—	—	±133
Winter Cabbage	5	Sandy	5,462	+510	+1,245	—	—	—	—	—	±350
Winter Cabbage	6	Sandy	2,727	—	—	—	—	+281	+360	—	±259
Wt. per Cabbage, lb.	—	—	1.25	—	—	—	—	—	0.0	−0.02	±0.038

(1) S.E. ±0.119. (2) S.E. ±0.536. (3) S.E. ±163.

†K stands for 1·3 cwt. K_2O per acre, as Sulphate of Potash.

Spring cabbages respond well to nitrogen as sulphate of ammonia at centre 1 (Avoncroft, Evesham) and 2 (Steppingley, Bedfordshire). At Steppingley, there is some indication that sulphate of ammonia was more effective than dried poultry manure but the difference does not reach significance. Savoy cabbages at centre 3 (Newport, Salop) show strong nitrogen responses and here the difference between sulphate of ammonia and poultry manure is statistically significant. At centre 4 (Dartington Hall, Devon) sulphate of ammonia increased the yield of broccoli heads and also the number per acre, the effect of dried poultry manure was smaller. At centre 5 (Potton, Beds.) nitrate of soda, applied to the previous early potatoes in this case, significantly increased the number of cabbages fit to cut on December 7th. There were no marked effects of phosphate or potash in the above experiments, and so far as they go they support the view that quick-acting nitrogen is likely to prove the most useful fertiliser for this type of crop.

The results for first early potatoes and root crops have been summarised in Table V. The figures for first early potatoes have been derived from a single farm, Potton, Beds., in 1931 and 1934. Experiments 1 and 2 were without dung; experiment 3 received dung. The crop was lifted early and proved very unresponsive in all cases. It is known from other experiments that first earlies left to stand till later in the season respond better to manures. Thus a crop at Little Downham, Ely, on fenland soil cut down by frost on May 17th, 1935, and left to stand till July 30th, gave an increase of 3.03 tons for 5 cwt. of sulphate of ammonia and 1.43 tons for 3 cwt. superphosphate per acre, both significant.

With the exception of a significant increase for poultry manure at centre 4 (Wye) and an improvement in the proportion of first grade bulbs at 7 (Swanley), onions have shown little response to nitrogen or phosphate in these experiments. Carrots have been surprisingly unresponsive in the roots; sulphate of ammonia and poultry manure generally reduced the yield and at centre 9 (Chittoe, Wilts.), the reduction was almost significant. Sulphate of ammonia increased the tops significantly at 10 (Woburn) and worked in the same direction at a second experiment at Woburn, 9. Plant number is significantly reduced by sulphate of ammonia in experiment 10. The very large yield in experiment 8 was the result of a dunged bare fallow in the previous year.

Red beet shows a good and significant response to sulphate of ammonia but less to dried poultry manure. The difference between the two manures although in the usual direction is not significant.

TABLE V

First Early Potatoes and Root Crops

Effect of Fertilisers

Centre No.	Soil	Mean Yield	Increase for N_1	N_2	M_1	M_2	P_1	P_2	K_1	Standard Error
First Early Potatoes		Tons								
1	Sandy	4.71	+0.14	+0.32	—	—	—	—	—	±0.170
2	Sandy	4.02	—	—	—	—	+0.25	−0.21	—	±0.175
3	Sandy	3.78	—	—	—	—	+0.14	—	+0.06	±0.124
Onions										
4	Chalk loam	7.64	—	+0.09	—	+0.86	+0.11	—	—	±0.332
5	Light	11.23	—	−0.06	—	+0.11	—	—	—	±0.452
6	Light	10.15	—	+0.03	—	+0.30	—	—	—	±0.407
7	Sandy	6.07	—	−0.25	—	+0.79	—	—	—	±0.691
		Per cent. 1st grade 66.4	—	+6.9	—	+6.0	—	—	—	±3.03
Carrots										
8	Sandy	Tons								
	roots	21.10	−1.20	−0.54	−0.20	−0.32	—	—	—	±0.722
	tops	9.23	+0.23	+0.94	−0.41	+0.57	—	—	—	±0.551
9	Sandy roots	10.52	—	−1.02	—	−0.77	—	—	—	±0.491
10	Sandy									
	roots	8.97	—	−0.63	—	+0.16	—	—	—	±0.421
	tops	3.42	—	+0.62	—	+0.29	—	—	—	±0.199
	Plant No.	Thous. 106.1	—	−5.0	—	−1.4	—	—	—	±1.422
Red Beet		Tons								
11	Loam	14.72	—	+2.10	—	+0.88	—	—	—	±0.800

Turning now to leguminous crops there have been five experiments on peas, one on French beans, and one on Runner beans. The results are summarised in Table VI.

TABLE VI

Leguminous Crops.

Year	Centre No.	Soil	Mean Yield per acre	Increase for N	M	P	K	Standard Error
Peas								
1933 ..	1	Sandy gravel	Peas cwt. 34.3	+3.50	—	−0.70	−2.45	±1.00
1934 ..	2	Light loam	,, ,, 77.0	+4.0	−1.2	—	—	±2.35
1934 ..	3	Sandy clay	,, ,, 46.8	−1.2	+5.4	—	—	±4.44
1934 ..	4	Silty gravel	,, ,, 93.9	−3.6	−4.1	—	—	±1.84
1934 ..			Haulm ,, 76.5	+2.9	−2.9	—	—	±1.37
1935 ..	5	Medium Loam	Peas ,, 96.7	−9.9	−4.3	—	—	±5.80
French Beans								
1935 ..	6	Sandy	Beans cwt. 45.1	+0.7	+9.4	—	—	±3.27
			Haulm ,, 61.6	+12.2	+29.8	—	—	±4.64
Runner Beans								
1935 ..	7	Alluvium	Beans ,, 39.7	+4.7	+5.0	—	—	±5.88

https://doi.org/10.23637/ERADOC-1-67

Peas have given very different results at the different centres. No. 1 (Stanford, Beds.) gave a significant response to quick-acting nitrogen, and the average response at centre 2 (Evesham) to sulphate of ammonia both in presence and in absence of poultry manure was $+4.9 \pm 1.66$ and therefore significant. On the other hand nitrogen in general reduced the yield significantly at centre 4 (Langford, Beds.), the effect was in the same direction also at 5 (Norton, Yorks.).

On French beans at 6 (Godalming) there was some indication of a response to poultry manure but none to sulphate of ammonia. Both manures give marked increases in haulm at this centre and in this respect poultry manure was significantly more effective than sulphate of ammonia. There were no effects on runner beans.

In experiment 1, phosphate in the form of basic slag had no effect on peas at Stanford, whereas potash significantly depressed the crop—an unexpected result on a sandy soil.

Experiments on miscellaneous horticultural crops have included lettuces, strawberries, celery, and apple stocks grown for vegetative reproduction. None of the manures tried had any effect on the number of lettuces fit to cut in spring ; in fact, their action was slightly depressing but not to a statistically significant extent. Manures applied to the parent apple stock in mid-June had no effect in the value of the offshoots, although sulphate of ammonia significantly reduced the value of the roots borne by the offshoots. It is possible that earlier application of fertilisers might have given better results.

Sulphate of ammonia was compared with poultry manure on strawberries and while the quick-acting nitrogen tended to depress the weight of total crop, the organic manure tended slightly to increase it, the mean difference being almost significant. Effects in the same direction were observed in the percentage of first grade fruits so that the final result was :

LONG ASHTON, 1934

First Grade Strawberries cwt. per acre

No nitrogen	5.91
Sulphate of Ammonia ..	4.30
Dried Poultry Manure ..	6.72

Celery proved to be a more responsive crop. The experiment at Mepal, Isle of Ely, on a light fenland soil in presence of farmyard manure showed definite increases in yield for superphosphate, sulphate of potash, and agricultural salt. Potash and salt also gave a significant improvement in the grading results. The figures relating to the above crops are given in Table VII.

The experiments summarised above give some information on the question of the relative precision of experiments on the vegetable crops as compared with ordinary farm crops. The average values for the standard error of a single plot expressed as a percentage of the mean yield have been determined by Yates*, for potatoes and sugar beet in recent randomised block and Latin square experiments at the outside centres, and these figures are given below together with general averages from all available Rothamsted experiments for swedes, mangolds and Kale.

---

*F. Yates, Suppt. Jn. Roy. Stat. Soc., 1935, 11p. 214.

TABLE VII

Miscellaneous Crops

Centre No.	Soil	Mean Yield per acre	N_1	N_2	M_1	M_2	P_1	P_2	K_1	K_2	Standard Error
Lettuces											
1	Medium Loam	No. thous. 33.3	−6.0	−5.9	—	—	−2.3	−3.8	−1.5	−3.7	±3.28
Apple Stocks											
2	Clay with flints	Value per stock, pence, 14.65	—	−0.48	—	—	+0.36	—	—	+0.10	±0.735
		Value of roots, pence, 0.92	—	−0.27	—	—	0.0	—	—	+0.08	±0.094
Strawberries											
3	Medium Loam	Total cwt., 17.9	−2.8	−4.6	+1.5	+1.2	—	—	—	—	±2.65
		First grade %30.7	−4.90	−4.61	+3.09	+0.74	—	—	—	—	±2.61
Celery											
4	Light Fen	Total tons, 8.32	Salt +0.43	—	—	—	—	+0.34	—	+0.89	±0.144
		Two Highest grades, %61.6	+3.9	—	—	—	—	−1.0	—	+4.0	±2.42

STANDARD ERRORS PER PLOT

Average Values as percentage of Mean Yields

	No. of Expts.	
Potatoes 1927-1933 Latin Square ..	56	6.8
,, ,, ,, Randomised blocks	22	9.2
Sugar Beet Roots Latin Squares ..	28	6.1
Randomised blocks	15	7.9
Swedes. Mean of all plot arrangements	8	6.9
Mangolds ,, ,, ,,	6	8.2
Kale	18	7.7

These values are rather uniform and it appears that for ordinary farm roots standard errors of about 7 to 8 per cent. may be regarded as normal.

In Table VIII below are collected the actual and percentage standard errors per plot of the vegetable crops discussed above.

TABLE VIII

Standard Errors of Experiments on Vegetable Crops, 1931-1935

(A) Full Sized Plots.

Crop	No. of Expts.	Standard Error per plot.	
		Actual per acre	Per cent of mean
Brussels Sprouts, total crop cwt.	11	3.83	10.1
Winter cabbages. No. fit to cut	2	518	13.2
Broccoli heads. Tons	1	0.29	18.6
Spring cabbages. Tons ..	2	1.04	12.1
Savoy cabbages. Tons ..	1	2.00	9.7
First Early potatoes. Tons ..	3	0.27	6.6
Carrots. Tons	3	1.08	8.7
Onions. Tons	4	0.92	11.9
Peas. Cwt.	4	4.02	7.5
Runner beans. Cwt.	1	11.76	29.6
Celery. Tons	1	0.35	4.3

(B) Microplots (1/145 acre or less).

Crop	No. of Expts.	Standard Error per plot	
		Actual per acre	Per cent of mean
Tomatoes. Total crop, tons ..	2	2.96	5.6
Apple stocks. Value, pence per stock	1	2.94	20.0
Lettuce. No. fit to cut, thous.	1	9.86	29.6
Pyrethrum. Dry flower heads, cwt.	2	0.92	15.6
Peas. Cwt.	1	8.20	8.5
French beans. Cwt.	1	4.62	10.2
Red beet. Tons	1	1.13	7.6
Strawberries. Cwt.	1	5.3	29.6

The most reliable value in this table is that for sprouts, which rests on 11 experiments. With a mean standard error of 10.1 per cent., this crop is slightly more variable than ordinary farm roots, possibly owing to the much smaller plant population per plot and the element of judgment entering into the several pickings. Nevertheless, a standard error of this size would be regarded as quite normal for certain farm crops such as cereals. Among other crops, broccoli and runner beans stand out as rather variable, while early potatoes, carrots, and peas have given values quite in keeping with those derived from ordinary potatoes and roots.

As might be expected the microplots show somewhat larger errors. The actual magnitude of the standard errors is the important figure for estimating the size, or cash value, of a difference that is likely to be detected by experiments of the kind under review. A well-designed experiment set out as a 6 by 6 Latin square will detect, as statistically significant, differences between treatment means of almost three-quarters of the standard error per plot. Smaller arrangements are less precise. The size and value of differences that would be judged significant in experiments of the precision of the Latin square are :—

Significant Differences per Acre

	Actual size. Cwt.	Approximate cash value. Shillings
Brussels Sprouts	2.7	34
Carrots	15	97
Onions	13	80
Peas	2.8	44

It is clear that the value of produce represented by a significant difference is quite large in relation to any probable expenditure on manures, so that with these high value crops the most efficient arrangements and fullest replication possible should be aimed at, so that treatment effects that are actually of high cash value and well worth having shall not fail to reach the level of statistical significance.

EFFECTIVENESS OF FERTILISERS

Our experiments show certain consistent differences between the three main groups of fertilisers. Nitrogenous fertilisers nearly always increase plant growth, though in many cases they produce their full effect only when potash and phosphates are also supplied. It is not usually possible to say beforehand whether these will be necessary or not ; soil analysis reveals the extreme cases of poverty but often fails to show the requirements on ordinary good farms. The effectiveness of potash and phosphate depends much more on soil and season than does that of nitrogen ; in 1935 some of the responses to potash were very marked, while others were not :

Comparison of Potash Response of Different Crops in 1935

				Mean Yield	Increase per 1.0 cwt. K_2O	% Increase
Six course rotation	Sugar beet.	Roots.	Tons	8.56	−0.24	−2.8
		Tops	,,	9.05	−1.55	−1.7
	Barley	Grain.	Cwt.	37.1	0.7	1.9
		Straw	,,	45.2	1.2	2.6
	Wheat	Grain	,,	25.3	3.2	12.6
		Straw	,,	42.0	6.2	14.8
	Potatoes		Tons	6.75	1.08	16.0
	Beans		Cwt.	21.0	2.7	12.9

Superphosphate was less effective than potash in 1935. Many experiments show that potash or phosphate can in certain seasons be omitted from the fertiliser without loss of crop, the necessary food being taken from the soil. But this process cannot be continued indefinitely ; if phosphate or potash starvation sets in it seriously reduces yields of important and expensive crops like potatoes. There may be times when the stored up fertility of the soil can be drawn upon and converted into cash, but as a regular procedure this may soon have undesirable effects. Now that rotations are not so strictly followed as before and farmyard manure is less readily obtainable it becomes important to watch the manuring closely and ensure that ample dressings are given for full crops and for maintaining the productiveness of the land.

MECHANISED CULTIVATION OF GRAIN CROPS

Problems arising out of the mechanised cultivation of arable land continue to receive attention. Both at Rothamsted and at Woburn deterioration of yield has followed from long continued growth of cereals on the same land where only artificial fertilisers are used, but the yields have been better maintained with farmyard manure. On modern mechanised farms and market gardens, little or no farmyard manure is made and therefore organic manure must either be brought in from outside or more or less dispensed with. For cereal growing it is not yet clear that this will matter very much for a few years, and good yields have been obtained without farmyard manure by suitable additions of artificial fertilisers, by occasional fallows and clover leys. For root crops, potatoes, sugar beet, for market garden crops and in some circumstances apparently for clover and lucerne, farmyard manure has special beneficial effects not easily obtained otherwise. Also on the lighter soils, such as those on which mechanisation is likely to be practised, the supply of organic manure is very important even for cereal growing. Two methods are being tried for increasing the supply of organic manure on the farm : green manuring and the return of straw to the land. The former is an old device, but very uncertain in its operation. The latter can be accomplished in various ways, several of which are being studied :

(*a*) Straw is being rotted in heaps by addition of the necessary nutrients for the micro-organisms ; this involves the difficulty of adequately moistening the heap.

(*b*) Straw is spread over the ground and ploughed in, the necessary artificial fertilisers being added either with the straw or later when they are likely to be most effectively used by the following crops. This method is being tried also at Sprowston on the farm of the Norfolk Agricultural Station.

In the Fermentation Department much work is done on the rotting of straw and other vegetable products to produce a good manure. This work continues to attract considerable attention, and workers come from overseas to study the possibilities of products available to them ; an Indian worker, Dr. Acharya, has in 1935 been investigating the rotting of rice straw. Organic manures, so far as they have been tested, have, however, less fertiliser value than the equivalent dressings of inorganic fertilisers.

Neither at Rothamsted, Woburn, nor on Mr. Prout's farm at Sawbridgeworth, were diseases or pests important, even after many years of continuous wheat growing. But in 1935 complaints reached us from mechanised farms of serious disease trouble even after 3 or 4 years only of wheat growing. Mr. Samuel found that the trouble was due to Take-all (*Ophiobolus*) or to *Fusarium*. By a curious coincidence, none of the three classical continuous wheat fields is liable to these diseases (though Take-all appeared at Woburn near the end of the experiment), but the light chalky soils on which mechanisation is developing are more susceptible to them. Mr. Samuel is taking up this question in detail.

Fallowing is, however, very effective in restoring productiveness to land deteriorated by continuous cultivation, though it is only temporarily beneficial. In general it makes a better preparation for wheat than clover or temporary leys. Unfortunately, fallowing favours the Wheat bulb fly (*Hylemyia coaretata*), and at the time of writing (May, 1936) the wheat crops sown after the fallows of 1935 are looking worse than any on the farm as the result of attacks by this insect, aggravated no doubt by heavy losses of soil nitrates during the very wet winter. Methods of control are being sought.

An important effect of fallowing is to keep down weeds and Dr. Brenchley has spent much time in discovering the conditions under which this is best done for the more important species. Chemi-

https://doi.org/10.23637/ERADOC-1-67

cal spraying methods are also being tried, and a series of experiments has been started, with quite interesting results so far, on the possibility of removing weeds from grassland by spraying.

SOIL CULTIVATION

The cultivation experiments have continued, and an extensive series of observations on rotary cultivation is being worked up.

Soil tilth has been studied from the field side in Dr. Keen's cultivation experiments and from the laboratory side by him and his assistants, Mr. Scott Blair, Mr. Cashen and Dr. E. W. Russell. The essential point is to bring the soil into an aggregation of crumbs and to prevent it falling into a state of dust. The actual changes depend on the drying and re-wetting of the soil and are brought about largely by the weather, but the implements play a vital part in putting the soil into such form that the weather can act. The field experiments have shown some of the differences between rotary cultivation and the older methods. They are now being extended to show how the soil moisture is affected by the various cultivation processes : this work is difficult because the Rothamsted soil, by its stony nature, is not readily sampled, and no method of estimating the moisture content *in situ* is yet free from objection.

The laboratory work has now reached a stage where the numerous facts are falling into order. An important test of value of any new development is the extent to which it can be used. These physical investigations have already proved of value to experts concerned with such diverse industries as flour milling and oil boring apart from their use in agriculture.

MINOR ELEMENTS IN PLANT NUTRITION

In 1923 Miss Warington proved definitely for the first time that a minute quantity of boron is essential for plant growth, and this result has already found applications in practice. Various crop diseases previously incurable have now been traced to a lack of available boron ; notably a heart rot in sugar beet and " Internal cork " in apples in New Zealand, " Top rot " of tobacco, and diseases of potatoes, turnips, tomatoes and other crops. These diseases may occur even when compounds of boron occur in the soil, but presumably the boron is unavailable, because they are cured by addition of a small quantity of borax. The subject is being further developed and several field experiments on sugar beet have been started in affected areas in consultation with us.

It is known that oats suffer from shortage of manganese on certain soil types, and the factors controlling the availability of the manganese in soils are being studied.

Small amounts of molybdenum salts are also shown to affect plant growth considerably, causing, in some cases, simulation of the symptoms of virus disease, and in others, the development of a trailing habit of growth where normally the growth is upright. These results are being further studied.

The effects of small quantities of nickel and cobalt salts are also being investigated.

COMPOSITION AND QUALITY OF CROPS

Owing to the impossibility of finding as yet any valid definition of quality, this work is done in association with the expert users of the crop, and their marks or grades, which are really measures of "commercial desirability," are accepted as the nearest measure of quality we are likely to get for the present. The buyers' grades have objective reality, for when the crop is converted into food, the resulting products show differences which vary in the same direction as the grades. So far as human food is concerned, we do not proceed to ascertain the physiological significance of these differences, but for animal food something can be done, though not yet as much as we should like because no satisfactory technique for grazing experiments in the field has yet been worked out. A beginning has been made, however, with experiments on pigs fed in pens.

The crops most investigated have been barley, potatoes, sugar beet and grass; and the expert bodies associated with the work were respectively the Institute of Brewing, Messrs. Lyons, the Beet Sugar Factory organisations, and the Basic Slag Committee of the Ministry of Agriculture. For the arable crops, the general result is that fertilisers used in the normal way will commonly increase the yields but do not affect the quality. Potassic fertilisers may effect some improvement in quality of crops grown for carbohydrates, and excessive dressings of nitrogenous fertilisers may reduce their quality. Beyond this there is no evidence that any system of manuring will bring about any significant improvement in the quality. For this the most important factors are the soil type and the season, and they have been fairly well characterised for barley. The conditions are unchecked growth, ample moisture during the spring, dry summers and good ripening and harvest conditions. For other crops the conditions are not yet so clearly defined, but it is known that suitable moisture supply and soil aeration are important.

Wheat

The technical applications of the earlier work on the physics of flour doughs have been extended by Mr. Scott Blair in co-operation with Dr. Halton of the Research Association of British Flour Millers at St. Albans. The aim of this investigation is to assess the bread-making quality of a flour by means of reproducible and impersonal tests on the dough. Hitherto the only test of quality has been the baking test, and this, even in the hands of a highly skilled baker, is subjective and unreliable.

The two most important properties required of a dough are adequate elasticity ("spring") and extensibility. The former depends on an optimum relationship between viscosity and elasticity modulus, and the latter, although not yet fully understood, is related to the way in which viscosity varies with stress. The bearing of these properties on bread making quality is being investigated. Doughs which tear easily, and consequently give bread with ragged crust and bad texture, are said to be "short." This property of "shortness," and the relationships between the breaking and the flowing of plastic materials, are being studied. Brittleness, which is disadvantageous in the flour-dough, is beneficial in the soil crumb, and the methods developed for the study of the dough are now being modified for application to the soil. The same principles are being applied at the National Dairy Institute for measuring the elastic and plastic properties of cheeses.

Flour doughs show a definite structure which is broken down on kneading, and re-establishes itself on standing. This property is fairly common and is called "thixotropy" (see also p. 64).

THE BIOCHEMISTRY SECTION 1933-1935

A. G. Norman

The work of this section consists in a study of the composition and decomposition of plant constituents, particular attention being given for the present to the carbohydrates.

Methods of Analysis of Plants

The conventional methods of analysis of agricultural materials give a very imperfect picture of the composition of a plant, being restricted usually to such determinations as ash, total nitrogen, (calculated as crude protein), ether-soluble material, and crude fibre, the difference of the sum of these from 100 being regarded as "soluble carbohydrates." Before any extended study of the composition of crops could be attempted, a more detailed and searching system of analyses had to be found to cover the carbohydrate constituents. This involved particularly the testing of methods for the determination of those structural constituents which are most inadequately represented by the crude fibre figures. The main structural constituents, cellulose, lignin and hemicelluloses, together account for the major part of any mature tissue. Existing methods have not been found to be generally applicable without modification.

1. *Cellulose*. The cellulosic framework of plant tissues is determined after removal of all other constituents. In fact, however, lignin is the most difficult component to remove. The Cross and Bevan procedure of alternate exposure to gaseous chlorine and extraction with boiling sodium sulphite is the basis of nearly all methods, the lignin thereby passing into solution as sulphonic derivatives. The conditions under which the chlorination may be carried out in dilute hypochlorite solution, have been examined,

https://doi.org/10.23637/ERADOC-1-67

and a more rapid and convenient method developed (1). The cellulose of plants and wood differs from that of the cotton hair in that it is not solely composed of glucose units, but contains also polysaccharides of other sugars, very intimately associated. These polysaccharides, which have been termed "cellulosans" (2) are more susceptible to hydrolytic agents, and more soluble in alkalis, than the true cellulose portion of the aggregate, so that all treatments other than with neutral solutions must be avoided if the integrity of the natural cellulose is to be preserved. The method devised is also suitable for making large-scale preparations of plant celluloses which was not possible previously. In most cases the associated cellulosan is xylan, which may be determined by the yield of furfuraldehyde from the isolated cellulose.

2. *Lignin.* The basis of the determination of lignin is the resistance of this substance to strong acids, in which cellulose and other carbohydrates pass into solution, subsequently to be hydrolysed. Existing methods, devised mainly for woods, have been shown to be inaccurate and quite inapplicable to agricultural materials, which unlike woods are often high in nitrogen. Two major and interacting sources of error have been shown to exist, due to the presence of pentoses and proteins. Pentoses or pentosans on contact with strong acids slowly give furfuraldehyde which in the absence of lignin condenses to form a black insoluble residue weighed as lignin (3) or in the presence of lignin unites with it to give a stable ligno-furfuran resin, thereby increasing the apparent lignin content. This disturbance may be minimised by shortening the period of contact with the strong acid, or by a hydrolytic pre-treatment (4). The error introduced by the presence of protein is at present more obscure and has not been wholly overcome. Proteins themselves or protein degradation products give no residue on treatment with strong acid but if added to a lignified material increase the apparent lignin content (5). Small quantities of protein cause a greater disturbance proportionately than do larger amounts, the error being due to the linkage with lignin of protein fission products of varying size. Acid pre-treatment results in a substantial reduction of the interference in most cases, which cannot be allowed for by calculating the nitrogen content of the lignin residue as protein and deducting. Because of these sources of error in the lignin determination the figures generally quoted for the lignin content of plant materials are in most cases too high.

3. *Hemicelluloses.* A satisfactory method for the routine determination of hemicelluloses has not yet been devised. Extraction methods that have been proposed are incapable of distinguishing between the true encrusting polyuronide hemicelluloses, and the cellulosan fraction of the cellulose, which has very similar properties.

(1) A. G. Norman and S. H. Jenkins—"A New Method for the Determination of Cellulose based upon Observations on the Removal of Lignin and other Encrusting Materials." Biochem. Journ., 1933, Vol. XXVII, pp. 818-831.
(2) L. F. Hawley and A. G. Norman—"The Differentiation of Hemicelluloses." Ind. and Eng. Chem., 1932, Vol. XXIV, pp. 1190-1195.
(3) A. G. Norman and S. H. Jenkins—"Lignin Content of Cellulose Products." Nature, 1933, Vol. CXXXI, p. 729.
(4) A. G. Norman and S. H. Jenkins—"The Determination of Lignin, I. Errors introduced by the Presence of Certain Carbohydrates." Biochem. Journ., 1934, Vol. XXVIII, pp. 2147-2159.
(5) A. G. Norman and S. H. Jenkins—"The Determination of Lignin, II. Errors Introduced by the Presence of Proteins." Biochem. Journ., 1934, Vol. XXVIII, pp. 2160-2168.

https://doi.org/10.23637/ERADOC-1-67

For the present and for comparative purposes, reliance is placed upon the yield of furfuraldehyde from the pentose and uronic acid groupings as a measure of the amount of encrusting hemicelluloses, this figure being arrived at by the difference between the total furfuraldehyde yield and that from the cellulosan groups in the cellulose.

The analyses mentioned above taken together provide a full picture of the structural constituents of any plant material and permit a detailed examination of the "crude fibre" determination, so much employed in agricultural analysis; by their aid it has been possible to show what exactly this fraction represents(6). The crude fibre figure may be very misleading since no constant or definite proportions of the structural constituents are included. The cellulose is partially attacked so that only 60 to 80 per cent. remains, and the lignin extensively removed by the acid and alkaline treatments given. Much variation may be found in the lignin content of crude fibre fractions. Since the presence of lignin exercises a direct effect on the digestibility of the material, any empirical method should include all the lignin. For certain purposes a simple acid hydrolysis would supply more reliable information than the crude fibre determination.

The Composition of Crops

Suitable methods having been devised a study of the composition of certain crop materials was commenced along the lines of a preliminary investigation carried out in 1930 on barley(7). Samples are cut at frequent intervals during growth so that the developmental changes may be followed. So far the investigations have been confined to winter wheat, and rye grass (Western wolths). The latter revealed several interesting features which are to be the subject of future examination. A high percentage of cold water-soluble material was found in this grass, at one stage nearly 55 per cent., and at maturity almost 40 per cent., the bulk of which is accounted for by a fructosan, or levan. At one stage the fructosan content was found to be 35 per cent. but as the grass approached maturity the amount of this constituent fell sharply while at the same time the cellulose increased. Neither the protein nor the lignin contents changed as widely as expected, and it is clear that a relatively small change in the amount of lignin present is responsible for the considerable decrease in digestibility that accompanies maturity. On drying for hay in the usual manner, the losses appeared to be of the order of 10 to 15 per cent., much of which could be accounted for by the disappearance of fructosan. Preparations of this fructosan have been found to be more susceptible to acid hydrolysis than any other polysaccharide, being completely broken down to fructose by heating with oxalic acid as dilute as 0.05 per

(6) A. G. Norman—"The Composition of Crude Fibre." Journ. Agric. Sci., 1935, Vol. XXIV pp. 529-540.

(7) A. G. Norman—"A Preliminary Investigation of the Development of Structural Constituents in the Barley Plant." Journ. Agri. Sci., 1933, Vol. XXIII, pp. 216-227.

cent. for one hour. Fructosans have also been found in wheat, though not to such an extent; apparently they have an important rôle in the metabolism of the Gramineae as a temporary carbohydrate reserve.

The Plant Cell-wall

Accompanying these applied studies of plant composition, some more fundamental work on the nature and inter-relationship of the cell-wall constituents has been undertaken, mainly on cereal straws and fibre plants.

1. *Cellulose.* It has been stated before that most plant celluloses are very different from cotton cellulose in that they are aggregates of pure cellulose and an associated polysaccharide or cellulosan, which is often xylan. Many plant celluloses have been isolated and their properties and stability studied with a view to obtaining information as to the method of association of the cellulosan, and its influence on the properties of the whole. The results are not inconsistent with the view that the cellulosan molecules, though much shorter in length, are oriented like the long cellulose chains and participate in the micellae, being retained by the same type of secondary valency forces. Heat drying liberates a water-soluble fraction, mainly of cellulosan, from a natural cellulose previously unaffected by water, and this phenomenon may be repeated many times. Any attack on the cellulosan such as acid hydrolysis or alkaline extraction is accompanied by a partial attack on the cellulose so that no hard and fast line can be drawn between the two groups. Solution and reprecipitation from a cellulose solvent, by destroying the orientation of the molecules, renders the cellulosans easily soluble. To obtain additional evidence on the distribution of the xylan in such celluloses, experiments have been carried out on certain vegetable fibres in conjunction with Mr. W. T. Astbury, of the University of Leeds, using X-ray methods. The removal of xylan progressively from manilla hemp cellulose was accompanied by an improvement in the X-ray picture indicating a more perfect crystallographical state. When freed from xylan, the diagram was almost indistinguishable from those of ramie and Italian hemp, both celluloses which are naturally very low in xylan(8). The diagram for isolated xylan has also been obtained by the preparation of thin films. The X-ray evidence is in accord with the view that the xylan molecules are iso-structural with those of the true cellulose chains.

In a study of the composition of vegetable fibres of many types, it was found that these fall into two well-defined groups according to whether the cellulose of the fibre was high or very low in xylan.(9) The group high in xylan includes the coarser fibres, such as jute, manilla hemp, and sisal, all of which contain also appreciable amounts of lignin and encrusting substances. The second group, low in xylan, includes the high-grade fibres such as flax,

(8) W. T. Astbury, R. D. Preston and A. G. Norman—" X-Ray Examination of the Effect of Removing Non-Cellulosic Constituents from Vegetable Fibres." Nature, 1935, Vol. CXXXVI, p. 391.

(9) A. G. Norman—" The Composition of some Vegetable Fibres, with particular reference to Jute." Biochem. Journ., 1936, Vol. XXX (in the press).

ramie and hemp. No direct relationship between xylan content and quality could be found in a wide range of jute samples.

2. *Lignin.* Arising out of the observation reported previously that lignin condenses with furfuraldehyde in the presence of strong acid, to give a complex of the nature of a phenolic resin, similar resins with a number of other aldehydes have been prepared. Imperial Chemical Industries have moulded the lignin-formaldehyde resin under high pressure. Phenol may further be condensed with the lignin-aldehyde complex with a resulting modification of properties. Lignin resins with acetaldehyde or higher aldehydes have not yet been tested commercially.

Considerable attention has been given to the delignification of plant materials by means of solvents. For many research purposes it would be desirable to achieve a complete removal of lignin without at the same time bringing about hydrolysis or degradation of the carbohydrates. Solvents such as pyridine, dioxan, alcohol, etc., have been tried, with, and without, previous chlorination, but so far only partial success has been achieved. The removal of lignin with alcoholic soda has been investigated since this has been proposed as a pretreatment to the preparation of the hemicelluloses, but neither cold nor hot is this an effective delignifying agent.(10)

3. *Hemicelluloses.* The encrusting polyuronide hemicelluloses are an important group in many agricultural materials; in straw, for example, they form the second largest constituent. The study of their composition is beset with difficulties, and all preparations are more or less seriously contaminated with lignin and cellulosan. To reduce the former, it has been customary to effect a partial delignification with alcoholic soda, but this has been shown to have at the same time a serious effect on the hemicelluloses, and particularly on those of immature tissues.(10) A study of the removal of lignin and hemicelluloses from the cell-wall by alternate chlorination and sulphite extraction has thrown some light on the condition of the hemicelluloses *in situ.*(11) It seems likely that there is some form of close association, probably amounting to actual chemical combination, between the hemicelluloses and lignin, since the former cannot be extracted unless a pretreatment (such as chlorination) is given capable of rupturing the linkage, or unless a solvent (such as alkali) is used which at the same time dissolves the lignin. The classical conception of the existence of a "lignocellulose" has had to be abandoned in view of modern work on the structure of cellulose, and it now appears that a lignin-hemicellulose complex may be substituted for it. Possibly both groups occur in two conditions, combined and free.

Decomposition of Plant Materials

The limitations of the lignin determination now being understood, it was thought worth while to take up again the question of the biological decomposition of lignin upon which subject many

(10) A. G. Norman—"The Hemicelluloses. I. Alcoholic Sodium Hydroxide as a Pretreatment to Extraction." Biochem. Journ., 1935, Vol. XXIX, pp. 945-952.

(11) A. G. Norman and (in part) J. G. Shrikhande—"The Hemicelluloses, II. The Association of Hemicelluloses with Lignin." Biochem. Journ., 1935, Vol. XXIX, pp. 2259-2266.

conflicting opinions have been expressed. Studies on the availability of lignin involve analyses from time to time on materials that are changing in composition. It is very significant that changes are especially marked in those two groupings which contribute so largely to errors in the lignin determination, for pentoses are rapidly fermented away and proteins synthesised under normal conditions of ærobic decomposition. To some extent these two errors are compensatory and their effect varies widely with the nature of the material and period of decomposition. Previous observations have been re-examined in the light of these facts.(12) The ærobic decomposition of lignin in straw has been studied and determinations made over a period of eighteen months by four different methods, all of which show losses of 40-50 per cent. of the lignin in the first year and 50-60 per cent. in eighteen months.(13) Lignin is certainly not so resistant to biological attack as has sometimes been claimed, but being the most resistant plant constituent tends to accumulate. Highly decomposed organic residues composed largely of lignin and protein are readily susceptible to oxidation, and this property is being investigated in humic residues from various sources.

Certain of the oak timbers of Rothamsted House have been very extensively attacked by the Death-watch Beetle, and on their replacement the opportunity was taken of analysing samples of the decomposed wood and comparing them with the sound wood from the same source. The results leave no doubt that the main constituent removed by the larvæ was the cellulose, and in so far as it was possible to form any estimate, the total loss suffered by the wood was in the region of one third.(14)

Other Investigations. The oxidation of amino acids with hypochlorite has been studied in detail, and the route of the reaction and products determined. Glycine gives rise to CO_2, water and gaseous N, through the intermediate formation of HCN, which is subsequently hydrolysed to formic acid and ammonia, both then being completely oxidised. The rate of the reaction is enormously affected by the *p*H of the mixture, being most rapid in the region of *p*H 7-9.(15) When extended to higher amino acids, this work has provided another example of the great disparity between the first and succeeding members in a homologous series, since the products and conditions of oxidation are very different from those found for glycine. The acids formed from the cyanide are not oxidisable, and from a dibasic amino acid, a cyano-acid has been obtained and identified.

DESIGN OF FIELD EXPERIMENTS

The earlier work of the Statistical Department included the designing of field experiments so that a valid estimate could be made of the magnitude of the errors affecting the results, and at the same time as much as possible of the variation due to soil irregularities

(12) A. G. Norman—"The Biological Decomposition of Lignin." Sci. Progress., 1936, Vol XXX, pp. 442-456.
(13) A. G. Norman—"The Decomposition of Lignin in Plant Materials." Trans. 3rd Internat. Cong. Soil Sci., Oxford, 1935, Vol. III, pp. 105-108.
(14) A. G. Norman—"The Destruction of Oak by the Death-watch Beetle." Biochem. Journ., 1936, Vol. XXX (in press).
(15) M. F. Norman—"The Oxidation of Amino-acids by Hypochlorite, I, Glycine." Biochem.. Journ., 1936, Vol. XXX, pp. 484-496.

could be eliminated. This purpose was accomplished, and designs such as randomised blocks and the Latin square are now superseding the older types of lay-out in almost all classes of agricultural experiment, both in this country and overseas.

During the last few years attention has been devoted to methods of increasing the efficiency attainable by simple randomised blocks and Latin squares, and to methods of widening the scope of a single experiment so that several problems can be investigated concurrently. *Factorial designs* have been developed, in which all combinations of different levels of several treatments (or factors) are included. A simple and very effective example of this type of design is the 27 plot experiments of the factory sugar beet series. In these experiments all 27 combinations of double, single and no dressings of each of the three standard fertiliser components, nitrogen, phosphate and potash are represented, only one plot being devoted to each treatment combination. Each plot is in effect used three times over, once to assess the value of nitrogen, once for phosphate and once for potash. In addition, information, which would be wholly lacking if three separate experiments, each confined to one of the three fertilisers, were used, is obtained on possible variations in response to one fertiliser at different levels of the other two. Such factorial designs, therefore, represent a great advance in experimental technique, and they will probably supplant the simpler methods in the same way as randomised blocks and Latin squares have supplanted the older systematic arrangements.

The attention of the department has also been directed to problems of sampling, which are of immense importance in agricultural experiments. The most efficient technique in any given instance can be determined only by statistical methods; indeed if statistical principles are not borne in mind sampling may be almost unbelievably inefficient. An example of the rapid advances in knowledge that can be obtained by the discriminating use of a good sampling technique, applied co-operatively by workers at several centres, is provided by the sampling observations of the growth of the wheat crop, which are described in a later section.

SOILS

The chemical and physical work consists in attempts to discover the composition and constitution of the soil, and to follow the changes taking place therein.

The clay is recognised as one of the most important components and much work is being done on it in the Chemical Department. Dr. Nagelschmidt has found by X-ray analyses that its commonest constituent differs from all known minerals, but is apparently related to halloysite: he is also studying the swelling of the montmorillonite lattice in presence of water. This investigation requires continuous access to very costly physical apparatus and we are greatly indebted to Sir William Bragg for allowing all that side of the work to be done in the Davy Faraday laboratory of the Royal Institution.

Soil Analysis. Considerable attention has been given to the old problem of finding some chemical means of forecasting the probable effects of fertilisers. For soils suffering from some serious deficiency this is relatively easy, but for soils that have been reasonably well farmed and manured none of the present methods is adequate. An examination of some 15 different methods was recently made by members of the International Society of Soil Science, but none of them proved entirely satisfactory. The rapid methods put forward from time to time are liable to give misleading results. Dr. Crowther, in conjunction with Mr. Warren, Dr. Richardson, Miss Heintze, Dr. Nagelschmidt and other members of his staff is examining the soils of the various plots on which sugar beet and potatoes are grown, to discover how far the results of the field experiments accord with the expectations based on various methods of chemical analysis.

Soil Moisture. In the Physics Department, a notable achievement has been the straightening out of the difficult problems associated with the moisture relationships of the soil. For many years these have caused considerable difficulty: a scale has now been devised which introduces the same kind of order and simplification as the *p*H scale has done for soil acidity. This work is so important to soil workers that a summary of it is given here though the description is necessarily very technical.

When wet soil is placed in an atmosphere of fixed relative humidity (h per cent.), evaporation continues until the moisture content has been reduced to a value which depends on the nature and previous moisture history of the soil sample and on h. When evaporation ceases, the free energy of the water remaining in the soil is less than that of pure water in bulk by $\frac{RT}{18} \log \left(\frac{100}{p}\right)$ ergs per gram. Dividing by the gravitational acceleration g, this free energy difference is given by the height in centimetres of a column of water that expresses, in effect, the "suction" with which the remaining water is retained; or, looked at another way, the effective height above a free water-table. Evaporation into a 50 per cent. relative humidity atmosphere develops a suction in the remaining water equivalent to 1,000,000 cm. of water, a column higher than Mount Everest. The difficulty of comparing such suctions with those developed as the result of drainage to a water table, which are of the order of 1,000 cm. and less, has been met by using the logarithms of these figures. By analogy with Sørensen's logarithmic acidity scale the symbol *p*F has been used (F being the recognised symbol for free energy).

The suction force exerted by the roots of plants which have just reached the "permanently wilted" condition is usually between 10,000 cm. and 20,000 cm., or between *p*F 4.0 and *p*F 4.3. There are great experimental difficulties in the way of measuring evaporation into atmospheres more humid than about 95 per cent. saturation Hence 60,000 cm., or *p*F 4.78, the suction developed by evaporation into an atmosphere over 10 per cent. sulphuric acid (95.6 per cent. relative humidity) is about the lowest value obtainable in this way. On the other hand, the highest value obtainable by vacuum suction through a filter is 1,000 cm., or *p*F 3. Fortunately, freezing point determinations enable this gap to be bridged. One degree centigrade freezing point depression corresponds to a suction of 12,700 cm. or *p*F 4.1.

Mr. Botelho da Costa, under the direction of Dr. Schofield, has used the improved freezing point technique mentioned in the last report to measure the *p*F of the water that remained in seven soils, of widely different character, when beans growing in them became "permanently wilted." The values so determined fell between *p*F 4.0 and *p*F 4.4, although the corresponding moisture contents ranged from 2.9 to 21.6 per cent. of dry soil. Taking the mean value of *p*F 4.2 and reading the corresponding moisture content from the curves plotted from the freezing point measurements, the values obtained differ on an average by only 0.7 per cent. from the moisture contents found in the wilting experiments. The greatest difference was only 1.2 per cent., which would be of small consequence in field measurements.

The moisture content of a soil at permanent wilting does not bear a constant ratio to the "moisture equivalent" determined in the Brigg-McLean centrifuge as these authors claimed. The freezing point determinations show why this is so. For a medium textured soil the "moisture equivalent" corresponds to about *p*F 2.9. This was confirmed by the freezing point measurements which showed that the curves connecting *p*F and moisture content differ in *shape* from soil to soil, and for the seven soils examined the ratio of the moisture content at *p*F 2.9 to that at *p*F 4.2, instead of being constant at 1.84, varied from 1.5 to 5.3.

By using the *p*F scale the results of measurements by direct suction, centrifuge, freezing point and evaporation into atmospheres of controlled humidity can be plotted on the same graph and curves connecting *p*F and moisture content can be traced from saturation (*p*F 0=1 centimetre suction) to oven dry (approximately *p*F 7). This work has brought into prominence the great importance of distinguishing between wetting and drying conditions. The suction needed to withdraw water from a moist soil is, in general, greater than that against which water will enter the soil at the same moisture contents. This fact, coupled with the slowness of wetting of clay by water at *p*F 3 or above, has been shown to account in a general way for the characteristic moisture distributions met with in the field.

SOIL MICRO-ORGANISMS

The growth of the plant, in nature is determined not only by chemical and physical soil factors but also by the soil micro-organisms, which are studied in the Micro-biological, Bacteriological and Fermentation Departments. The more these organisms are investigated, the more numerous they appear. Twenty-five years ago, the bacterial population in one gram of soil (about a salt-spoonful) would have been assessed at about 5 to 10 millions. It is now known that the figures are very much higher. A gram of field soil may contain several thousand million bacteria, many thousands of protozoa, millions of actinomycetes and fungi, in addition to an unknown number of eel-worms, besides other organisms not invariably found, either because they are not always present or because the technique is defective. The greater accuracy of modern bacterial counts is due to the method of counting bacterial cells in soil under the microscope which has been developed in the Bacteriology Department and now gives reliable quantitative results.

Three main groups of investigations are carried out :—

1. The decomposition of organic matter and its conversion into simpler substances. This is at the basis of the production of plant food in nature, but it has also many applications on the farm and in the countryside ; three of which are studied in detail :

(*a*) The decomposition of plant residues in the soil in relation to green manuring, ploughing-in of leys, residual values of farmyard manure.

(*b*) The conversion of straw and other plant residues into organic manure. This process has been taken up by Adco, Ltd., and developed by them into a workable process for making artificial farmyard manure. While English farmers do not make much use of it the method is used a great deal by gardeners and to a still greater extent by planters and growers overseas. Some 50,000 tons or more of manure are probably made annually through this one organisation and there is reason to believe that the total made in all countries by the process is not less than 200,000 tons annually.

(*c*) The biological purification of effluents from sugar beet and milk factories.

The last-named investigation is carried out in the Microbiological and Fermentation Departments under the ægis of the Department of Scientific and Industrial Research ; the work is done partly at Rothamsted and partly in the factory.

In the Bacteriological Department the interesting work on clover organisms continues, and it is shown that in the soils of certain hill districts there occur harmful strains which do not themselves benefit the clover plant, and which prevent most beneficial strains from forming nodules. A few beneficial strains, however, are able to overcome the harmful effects of the bad strains and enable the plant to make full normal growth. Experiments have been begun on the inoculation of these beneficial strains into soils containing the harmful ones, and the results are distinctly promising. The first essential is a survey of the hill districts to see how far these harmful strains are prevalent, and to what extent the highly efficient strains already isolated are able to act generally in overcoming their bad effects.

The process of infection has been studied in considerable detail. It is impeded by the presence of nitrates which not only reduce infection but also reduce the activity of nodules already formed. Part of the effect consists in checking the deformation of the root hairs which is an essential preliminary to infection : this, however, can be counteracted by adding dextrose. Such nodules as are formed in presence of nitrate are abnormal in several ways. The distal cap of the cells, normally thin-walled and actively dividing, develops much thickened cell walls and the cell-division soon ceases. The lateral endodermis and the cells surrounding the vascular strands become heavily suberised. These changes result in the central nodule tissue becoming enclosed in a layer of thick walled cells. This central tissue shows evident signs of starvation.

PLANT PATHOLOGY

Virus Disease. The group of workers who have since 1929 studied virus diseases under Dr. J. Henderson Smith, suffered its first loss in October, 1935, when Dr. John Caldwell left to take up the Lectureship of Botany in University College, Exeter. His last important contribution was to show that inoculation with a strain of virus conferred in certain conditions some degree of immunity against a virulent strain of the same or a closely allied virus. Dr. Sheffield, in studying by micromanipulative technique the localisation of virus in the plant and within the single cell, has found that individual cells differ in susceptibility to virus attack, only 6-12 per cent. of injected cells responding to inoculation.

Mrs. Watson has carried out a series of quantitative investigations on the relations between the insect vector and the infection it produces. The amount of infection increases as the time of feeding the infected insect on the healthy plant is raised from 2 minutes to 12 hours, but only by about 20 per cent. As the time of feeding on the infected plant, before transference to the healthy plant, is increased from 2 or 5 minutes to 1 hour, the amount of infection falls by 50 per cent., but rises again after 1 hour's feeding. The fall may be due to development of an antibody in the insect body and this is being investigated with the help of Miss B. Mitchell. An infected insect, transferred from one healthy plant to a second, may infect the second plant as well as the first, but not if the period on the first plant exceeds one hour. This is of importance in the question whether insect transference with viruses of the type under experiment is purely mechanical or requires ingestion by the feeding insect.

Mycology. A new glasshouse for mycological work was completed in October. It includes one large compartment, 24 ft. by 30 ft., for general mycological work, and four small compartments, 11 ft. by 11 ft., which can be made insect-proof when required. Heating is by a thermostatically controlled, oil-fired boiler. The new house has already proved that it is excellently adapted for the work required.

The completion of this house enabled investigations to be commenced towards the end of the year on the club-root disease of crucifers. It is proposed to examine first the well-known action of lime in controlling the disease, and to determine if possible whether this is due to an effect on the disease-producing organism itself, or whether it is due to an increased resistance conferred upon the host plant. An effort will also be made to find an explanation for those cases in which lime is stated to have no beneficial effect.

The work on root-rot diseases of cereals has been continued. F. J. Greaney, on leave from Canada, co-operated with G. Samuel in an investigation on the gradual invasion of wheat root systems by fungi as the crop ripens. They found that the fungus *Fusarium Culmorum*, which is usually regarded as a disease-producing organism was much more widely distributed than was imagined, and that healthy wheat crops by the time they were reaped often had a considerable amount of the fungus present on the roots without suffering any apparent harm. Studies will be made later of the conditions under which this fungus becomes a parasite of importance.

ENTOMOLOGY

The Entomological Department is concentrating on a study of the factors that determine the changes in number and the movements of insect populations. Observations show that all the ordinary harmful insects occur on our farm but in general their numbers are so small that they do little damage. Occasionally, however, one or more species multiplies with extraordinary rapidity and devastates the crop. The spring of 1935, for example, was not favourable for insects in general, yet one species, the Pygmy Mangold Beetle, multiplied so inordinately that it completely ruined the mangolds on Barnfield, on which mangolds have been grown every year since 1876 (with two exceptions) and where the insect has certainly been living for a long time. In certain investigations, the general procedure is to take systematically frequent "samples" of the insect population of the farm. Methods have been devised for making sample censuses that can be subjected to statistical examination and these are continuously improved to facilitate their use in practice. Approximately four times as many insects were caught from March to October in 1935 as in the corresponding period of the previous years, the difference being mainly in the Lepidoptera and the Diptera. Full meteorological observations are taken, and relations are sought between these and the census figures. The numbers of nocturnal insects caught in a light trap show a definite lunar periodicity, with low numbers at full moon and high numbers at new moon. The effect is more marked for some groups of insects than for others and is most significant in the *Noctuidae*.

A higher proportion of females was obtained in the *Noctuidae* in a trap at a height of 35 feet above the ground, than in one about 3-4 feet above the ground.

A mechanical trap for insects, designed and tested during the year has been found valuable for estimating the activity of small slow-flying insects, such as green fly. It has already been adopted for use in studying the transmission of potato virus disease by insects.

Dr. Barnes has completed the first series of his studies on variation in population of certain insects, which include nine years' observations in the case of the wheat midges. The figures for 1935 for the latter insect show an increase over the previous two years and so fit very closely to the periodic curve which was suggested three years ago.

The analysis of records of insect migration has thrown light on two important problems. Considerable evidence has been found that some British migrant butterflies and moths make a return flight to the south in the autumn, also that one of the migrant Hawk moths which occurs in both Europe and America, at times as a pest, shows a tendency to occur simultaneously in both Continents. This indicates that the causes of migration in this species must be sought for in factors that are either very widely spread or are positively correlated in the two Continents.

INSECTICIDES.

Dr. Tattersfield and Dr. Martin investigate the direct attack on harmful insects by means of insecticides. Certain vegetable products are found to be extremely effective and have the further advantage that they are harmless to farm animals and to man. Among them the most important are products from the tropical plants, Cubé, Derris, Haiari and others, and the non-tropical Pyrethrum. Methods of chemically evaluating these are investigated, and experiments are made to test the effect of manures on pyrethrum. Dr. Tattersfield's work has created so much interest in the United States that one of the large manufacturing firms there invited him over in May, 1935, to discuss problems with their experts and those of the United States Department of Agriculture.

During 1935 work has been concentrated on the differentiation of the species and varieties of derris root. Henderson's valuable studies in Malaya of the botanical characters of members of this genus give no indication of their potential value as insecticides nor whether the constitution of the resins is determined by genetical or environmental factors. We have had specimens of *Derris elliptica* possessing little or no toxicity to insects, and samples of *Tephrosia vogellii* and of *Mundulea suberosa* vary widely in activity, despite the fact that they appear to be true to type. From these plants a number of crystalline derivatives have been isolated by various investigators. Only one, " rotenone," is highly toxic to insects, the others appear to be either altered in the process of extraction or derived from precursors of greater insecticidal power. Three samples of derris, *D. elliptica*, *D. malaccensis*, and the " Sumatra-type," all contained about the same amount of extractives, but the resins differed markedly in properties. The rotenone content was highest in *D. elliptica* and lowest in the "Sumatra-type." *D. malaccensis* and the "Sumatra-type" resins yielded an optically active resin from which was isolated optically inactive " toxicarol," a compound closely related to rotenone, but with relatively little insecticidal power. The resins derived from these three types of root when dissolved in benzene were optically active and laevorotatory, and although their rotations were in the same order as their insecticidal powers the relationship was not quantitative. When a solution of caustic potash in methyl alcohol was added to the benzene solutions of the resins, those derived from *D. malaccensis* and the " Sumatra-type " changed instantaneously in sign and became dextrorotatory, while those from *D. elliptica* became less laevorotatory but did not change sign. The resin extracted by caustic potash from the " Sumatra-type " resin gave the change-over from laevo- to dextrorotation, but the residue reacted like the resin from *D. elliptica*. The induced dextrorotation declined with time at a rate depending on the amount of methyl alcohol added with the potash.

Direct insecticidal tests showed that no single method, including the estimation of the dehydro-compounds derived from the resins by suitable oxidation and dehydration processes, truly assessed the relative potencies of these three roots, and our chemical work shows that the toxicity of the resins is determined not only by rotenone, but by the precursors of deguelin and toxicarol also.

In the field experiments on pyrethrum at Woburn manuring had no significant effect on yield.

Soil Insecticides. The possibility of finding a chemical substance effective for soil sterilisation and as a soil insecticide has recently been revived. Some years ago it was shown at Rothamsted that certain benzene derivatives were very promising, but they were then unobtainable on the large scale. They are now, however, available in quantity and at relatively low cost. The subject has therefore been re-opened and Major Ladell appointed to discover how best to find out the effects of these substances against wireworm and eel-worm in actual field conditions; these two pests being chosen because they are already doing much damage, and the eel-worm is threatening to do more.

This work has been greatly facilitated by Major Ladell's new method for the rapid separation of insects and other arthropods from soil. The sample is stirred in a heavy non-toxic solution (magnesium sulphate, sp, gr. 1.1) through which a stream of fine air is bubbled to assist in floating the insects to the surface. The froth containing the insects is drawn off over a sedimentation tank and the insects finally separated by filtration.

Over 95 per cent. of the soil fauna can thus be separated from a sample of about 5 lb. of soil in about 20 minutes. Two field experiments on the use of insecticides against soil insects were carried out in 1935, one against wireworm and the other against root eelworm, four insecticides in single and double doses being used. Significant differences were observed between the numbers of eelworm cysts in the control and some of the treated plots. There was also a noticeable decrease in the number of wireworms on some of the plots. Both experiments are being continued.

BEE-KEEPING RESEARCH SECTION: 1922-1935.

Organisation and Equipment. Shortly after the war the Development Commissioners made a grant to the University of Cambridge for investigations on problems of bee-keeping to supplement the work on Bee Diseases they were financing at the University of Aberdeen.

In 1921 the investigations were by mutual agreement transferred to Rothamsted along with the equipment and the stocks of bees. In 1922 Mr. D. M. T. Morland came from the Ministry of Agriculture to take charge. He has been assisted throughout by Arthur Rolt, while B. A. Young was a voluntary worker for about one year and others for shorter periods. In 1934 the beekeepers asked that the work should be extended to deal with bee diseases, and the British Bee-Keepers' Association generously undertook to collect one half of the money required, if the Ministry of Agriculture would provide the rest. This was done, and Dr. H. L. A. Tarr was appointed as Bacteriologist to investigate brood diseases.

The section forms part of the Department of Entomology.

At the inception of the work at Rothamsted an Advisory Committee was appointed consisting of Messrs. Bocock, J. C. F. Fryer, Cragg and W. Herrod-Hempsall, with Sir John Russell as Chairman and Dr. Imms (Head of the Department of Entomology) as Secretary. Meetings have been held once or twice a year to discuss the progress made and to advise on future investigations.

The present Committee consists of Mr. J. C. F. Fryer, Mr. W. Herrod-Hempsall (Ministry of Agriculture), Miss A. Betts (Apis Club), Dr. Gregg, Mr. J. Herrod-Hempsall, Rev. W. H. Richardson (British Bee Keepers Association), Dr. H. Schütze, Dr. J. C. G. Ledingham (Lister Institute), Brother Adam, Dr. F. Thompson, Mr. B. C. Berkeley, Mr. Gilbert Barratt. Two of the members representing the B.B.K.A. were appointed by that body when they took over the responsibility for the collection of the Beekeepers' share in the fund for Foul Brood disease research : the two members representing the Lister Institute were appointed at the same time to advise on the bacteriological side of the work.

The experimental apiary (4)[1] is situated on the Rothamsted Farm in a sheltered position protected by trees and hedges. It usually contains thirty to forty colonies mostly on British Standard Frames, about half being in W.B.C. hives and the rest in "National" single walled hives. These are arranged regularly, but in such a way as to avoid excessive drifting of the bees. The field laboratory contains store room, extracting room, and workshop and has water and electricity laid on.

Two or three out-apiaries are usually maintained for special investigations and for work on brood diseases.

The main sources of nectar are white clover, the lime trees of the adjacent avenue and, in spring, wild cherry and holly. Willows of both pollen- and nectar-bearing varieties have been planted at the apiary and a small orchard stands opposite. The spraying experiments carried out on these trees are watched with some anxiety, but up to the present there has been no evidence of poisoning of the bees.

For the more technical investigations there is a large laboratory in the Entomological Department.

Hive Temperatures. Observations on hive temperatures by means of thermocouples were commenced by Mr. Bullamore while the apiary was still at Cambridge ; they were continued at Rothamsted with improved instruments embedded in the foundation wax. Interference with the brood was thus avoided but the temperatures recorded were of course those of the brood and not of the air in the hive.

Daily readings, winter and summer, were carried out for a number of years in hives with different comb arrangements. Once a month readings were taken every three hours for a period of 24 hours or more. The statistical analysis of the data was made under the supervision of Mr. Irwin, but was never published. The results tended to confirm those obtained by Phillips and Demuth in North America and were summarised at the 5th International Entomological Congress in Paris in 1933 (15).

Feeding Experiments. Two feeding investigations were undertaken in 1929(10), these were :—

(*a*) *Comparison of Cane and Beet Sugar.* Some beekeepers had

(1) The numbers in brackets refer to the Bibliography on pp. 64—66.

been accustomed to attribute their winter losses to the use of beet sugar as food. Two series of hives were deprived of most of their natural stores, one was given cane sugar first as syrup then as candy, and the other beet sugar in similar form. No difference in wintering attributable to the sugar could be detected. This experiment was repeated over a series of winters.

(*b*) *Ripening of Syrup*. A mild organic acid such as tartaric acid or vinegar is sometimes used in preparing syrup for autumn so as to invert the cane sugar and prevent granulation in the comb. Experiments showed that boiling syrup with acetic acid for 30 minutes inverted only 15 per cent. of the sugar, while merely bringing the syrup to the boil was almost ineffective. Syrup to which acid has been added was not so readily inverted by the salivary juices of the bees as was the plain sugar, so that samples of the sealed stores taken from the hive after feeding showed an advantage in favour of the untreated sugar. The inhibiting action of the acetic acid on the invertase of the bees' saliva had defeated the object of adding it.

Weighing Hives. Even in a commercial apiary it is most desirable to have a hive on scales, and in an experimental apiary this is a necessity. Three sensitive self-recording balances are used to record continuously the changes of weight of the stocks kept on them([8]). One of these has been in continuous use for nine years and the records show a marked similarity in the dates of the onset, peak and cessation of honeyflow in different seasons.

The relation between the daily fluctuations, which give a measure of the bees' activity, and the weather records (sunshine, temperature, rain, wind, in decreasing order of importance) have been studied by P. V. Sukhatme.

Study of Swarming. Swarms are undesirable as they not only cause trouble and loss of time, but also they divide the working force of the bees at the season when it is most important to keep it intact. The brood food theory of Gerstung seems to offer a reasonable explanation of swarming and it has received some confirmation from Rösch's work on the division of labour in the hive([12]).

Experiments with bees marked on emerging from the cell and then introduced into observation and other hives, tend to corroborate Rösch's work. As they become older bees are promoted from the various grades of nursing duty to household work, such as wax building and the ripening and storing of honey, and finally to field work.

According to the brood food theory it is a surplus of nurse bees over the requirements of the brood that causes the building of queen cells. A surplus occurs in every normal stock immediately after the peak of brood rearing is reached; its magnitude varies according to a number of factors and it is largely this which determines whether swarming occurs or not.

The introduction of marked bees into a colony induced swarming: indeed in one year the only swarms in the experimental apiary came from such colonies. The withdrawal of brood from other strong colonies to provide bees for marking and transfer to the experimental hives had lowered the proportion of nurse bees to brood in the one lot and considerably augmented it in the other. Removal of much of the sealed brood from the nest and keeping the resulting bees away until they are past nursing age forms the basis of several systems of swarm control.

A Conference on swarming was held at Rothamsted in 1935 and was largely attended by beekeepers. A report on this Conference was published(38).

Bee Diseases

Acarine or "Isle of Wight" Disease. In 1927 Mr. Allen experimented on the treatment of Acarine disease by vapours introduced into the hive. Oil of wintergreen and sulphur dioxide were the only ones that killed the mite without at the same time killing the bee. The Frow treatment had not at that time been devised and nitrobenzene was not tried ; when Mr. Allen left the work was discontinued ; it will, however, be resumed during the coming season.

Brood Diseases. Dr. Tarr finds that American foul brood is a definite disease due to *Baccilus larvae,* but the so-called European foul brood is more complex and appears to be associated with at least two organisms. A third disease generally called "addled brood" may be due to some trouble in the queen and is not due to a pathogenic organism.

American foul brood and addled brood are more common than European foul brood.

American foul brood appears to attack quite strong bees, but there is distinct evidence that European foul brood is more prevalent in weak stocks and in neglected apiaries.

A Conference to discuss problems of brood disease was held at Rothamsted in May, 1934(37).

Senses and Sense Organs of Bees. H. C. F. Newton investigated the so-called olfactory organs or "campaniform sensillæ" scattered over the bodies of bees, dealing particularly with the structure and development of the sensillæ occurring in the wing bases of adult worker bees. He finds no evidence that the actual termination of the nerve fibre is exposed to the outside air.(23)

J. Marshall(2) has made a preliminary study of other sensory organs, the contact chemoreceptors on the antenna and fore-tarsus of the honey bee. He found that the bee responds when a solution of saccharose of an average strength of M/12 comes into contact with the antenna, whereas a strength of M/1 is required to elicit a response from the fore-tarsus. Amputation of the antenna did not affect the gustatory reactions of the bee but resulted in a complete loss of olfactory recognition of wax comb. It was concluded that the antenna are the seat of all the olfactory organs which perceive mild odours.

Honey Problems

"Frosting" of Granulated Honey. Preliminary observations suggest that this phenomenon, due to the formation of an irregular air space between the dextrose crystals and the jar, is aggravated by the large quantities of air that the modern centrifugal extractor incorporates into the honey and which is not removed in subsequent operations. It can be got rid of by incubating for two days at 40°C, but this involves loss of both colour and aroma of the honey. Placing the honey in a vacuum was not effective as on re-admitting air the bubbles were re-absorbed.

Heather Honey. Thixotropy. Heather honey is popularly supposed to be able to hold more moisture than other honeys without fermentation, and it was therefore desirable to draw up for the National Mark Scheme a special schedule for heather honeys, allowing a reasonable excess of moisture. The special water-holding powers are associated with the capacity to form a gelatinous structure on standing which is reversibly destroyed by stirring, a property well-known in other materials under the name of "thixotropy" (page 47).

G. W. Scott Blair has investigated this problem and has described a simple semi-quantitative test for thixotropy by which honeys can be classified (24).

Very few of the many plants from which honey can be obtained yield this thixotropic honey. *Calluna vulgaris* and *Leptospermum scoparium*, the latter from New Zealand, are the only authenticated cases to date (Apr., 1936), except that heated honey from Buckwheat (*Polygonum fagopyrum*) is also reported by Pryce-Jones as thixotropic.

Honeys produced from *Erica* spp. however, are not thixotropic, and should not contain any excess of moisture.

Library

A library of bee-keeping books is being built up and now includes long series of some of the more important bee journals and a number of books and pamphlets on beekeeping. Additions to the collection will be welcomed.

Papers Published from Rothamsted on Bees: 1926—1935

1. Barnes, H F (1934). "Lestodiplosis alvei sp.n. (Diptera, Cecidomyidæ) from Bee Hives." Parasitology 26, pp. 594-595.
2. Marshall, J. (1935). "On the Sensitivity of the Chemoreceptors on the Antenna and Fore Tarsus of the Honey-bee." Jour. Exp. Biol. 12, pp. 17-26.
3. Morland, D. (1926*a*). "Moisture in the Hive." Somerset Beekeepers Association Annual Report, 1925, pp. 24-27.
4. Morland, D. (1926*b*). "The Bee Research Institute at Rothamsted. Jour. Min. Agric. 33 (Apr.), pp. 33-38.

5. MORLAND, D. (1926*c*). " On the Microscopic Examination of bees for Acari. Ann. App. Biol. 13, pp. 502-505.
6. MORLAND, D. (1927). " Beekeeping." Year Book, Essex County Farmers Union, 1927, pp. 218-222.
7. MORLAND, D. (1927). " Scientific Research and Beekeeping " (Lecture before the 5 Counties Convention at Malvern.) Scottish Beekeeper 4 (Aug.), pp. 24-25.
8. MORLAND, D. (1929*a*). " A Recording Scale for Beehives." Ann. App. Biol. 16, pp. 294-298.
9. MORLAND D. (1929*b*). " Why do bees swarm ? " Report of convention of beekeepers at Leamington Spa, pp. 7-10.
10. MORLAND, D. (1929*c*). " The feeding of bees." Journ. Min. Agric. 35, (Jan.), pp. 945—950.
11. MORLAND, D. (1930*a*). " Artificial feeding." Somerset B.K.A. Ann. Report, 1929, p.19.
12. MORLAND, D. (1930*b*). " On the causes of swarming in the honey bee, an examination of the brood food theory." Ann. Appl. Biol. 17, pp. 137-149.
13. MORLAND, D. (1931. " A drinking fountain for bees." Bee World, 12, pp. 50-51.
14. MORLAND, D. (1932). " The foul brood controversy." Kent B.K.A. Yearbook, pp. 24-25.
15. MORLAND, D. (1933). " Temperature in the beehive." 5th Internat. Congr. Ent. (Paris), pp. 879-981, also in Bee World, 15, pp. 98-99.
16. MORLAND, D. (1933). " The feeding of bees." Bee Kingdom 4, pp. 92-97. (Reprinted from Jour. Min. Agric. (England 1929).
17. MORLAND, D. (1933). " More about swarms." Rept. Convention of beekeepers Cheltenham.
18. MORLAND, D. (1934). " Sting of hive bees." Letter in " Nature," Oct. 1934.
19. MORLAND, D. (1936). " Bees and the dairy farm." " Farming," Jour.S.E. Jersey Club, (Feb.), p.20.
20. MORLAND, D. (1933). " Distribution of foul brood in England." Rothamsted Conference XVIII : Brood diseases of bees, pp. 8-16, 1 fig.
21. MORLAND, D. (1934). " Brood diseases of bees." Rothamsted Conference XVIII : Appendix, pp. 41-46 (also printed separately).
22. MORLAND, D. (1935). " Swarming and the division of labour in the hive." Rothamsted Conference XX : The cause and control of swarming in bees, pp. 14-17.
23. NEWTON, H. C. F. (1931). " On the so-called ' olfactory pores ' in the Honey Bee." Quart. J. Micros. Science 74 (4), p.647-668.
24. SCOTT BLAIR, G. W. (1935). " The thixotropy of heather honey." Jour. Phys. Chem. 39, pp. 213-219.
25. TARR, H. L. A. (1934). " Summary of foul brood disease investigation report for May 1st to September 1st, 1934." Bee World, 15, No. 12. (Also in Bee Craft and British Bee J.).

E

26. TARR, H. L. A. (1935). " The Brood Diseases of Bees." In Report of the lectures given at the fifteenth Midland and South Western Counties Convention of Beekeepers. Worcester, p.21.
27. TARR, H. L. A., 1935. " Studies on European foul brood of bees, I." A description of strains of *Bacillus alvei* obtained from different sources, and of another species occurring in larvae affected with this disease. Ann. App. Biol. 22, pp. 709.
28. TARR, H. L. A. (1935). " A note concerning the brood disease investigation at Rothamsted Experimental Station." In " Year Book of the South Eastern Federation of Bee Keepers' Associations," p.5.
29. TARR, H. L. A. (1936). " Abridged Report of the foul brood investigation for September 30th, 1934, to September 30th, 1935. Bee World, No. 1. (Also in Bee Craft and British Bee Journal and Archiv. f. Bienenkunde 17, 92).
30. TARR, H. L. A. (1935-6). " Brood diseases of bees." Beekeeping 1, No. 7. Vol. 2, Nos. 1 and 2.
31. TARR, H. L. A. (1936). " The organism of European foul brood of bees." Nature, 137, p. 151.
32. TARR, H. L. A. (1936). " Streptococcus apis Maassen." Bee Craft, No. 2. (Also in British Bee Journ. and Bee World).
33. TARR, H. L. A. (1936). " Bacillus alvei and Bacillus paraalvei," Bee World, No. 4. (Also in British Bee Journ. and Bee Craft.)
34. TARR, H. L. A. (1936). " The diseases of bee larvae." In Bee World, Bee Craft, and British Bee Journ.
35. TARR, H. L. A. (1936). " Studies on European foul brood of bees, II." The production of the disease experimentally. Ann. Appl. Biol. 23. (In the Press.)
36. TARR, H. L. A. (1934). " The present position of the Scientific Investigation of foul brood diseases of bees." Rothamsted Conference XVIII.,
37. (1934). Rothamsted Conferences 18 : " Brood diseases of bees," 46 pp.
38. (1935). Rothamsted Conferences 20 : " Cause and control of swarming," 31 pp.

CROP ESTIMATION AND FORECASTING

SAMPLING OBSERVATIONS ON THE GROWTH OF WHEAT

In 1924 the Agricultural Meteorological Committee was formed by the Ministry of Agriculture and Fisheries, the Department of Agriculture for Scotland, the Meteorological Office and the Forestry Commission, to investigate the effects of the weather on agricultural and horticultural crops. The programme includes sampling observations on the growth of wheat on a plan developed by the Statistical and Plant Physiological Departments at Rothamsted. Ten stations collaborate ; at nine of them full meteorological observations are taken. The work is supervised by the Statistical Department, and 1935 was the third year of the full scheme.

The observations consist of counts of plant number and shoot number per unit area, and measurements of shoot height and ear height. At each station two standard varieties are observed at intervals varying from three weeks to a day, according to the state of the crop.

In surveying the results of the first three years Miss M. M. Barnard found a close connection between the height of the shoots at ear emergence and the final yield of grain. Plant number at tillering was negatively correlated with the yield of grain. No other measurement was closely associated with yield. The results are too few to show the effects of variation in meteorological conditions on yield, but at certain stages the effect of the temperature on growth was clearly marked. The wheat crop, in fact, appears to be growing at or near the optimum meteorological conditions, so that the influences of variation of weather are likely to be small and complex, differing with different soil types.

Observed and Predicted Yields (cwt. per acre)

Station	1932-33		1933-34		1934-35		Mean	
	Ob-served	Pre-dicted	Ob-served	Pre-dicted	Ob-served	Pre-dicted	Ob-served	Pre-dicted
Seale Hayne ..	19.0	25.5	32.4	30.0	26.2	26.2	25.9	27.3
Rothamsted ..	22.2	26.2	32.2	32.4	34.7	32.5	29.7	30.4
Newport ..	35.3	38.8	43.7	43.3	40.0	37.6	39.7	39.9
Boghall	32.8	35.3	35.7	37.8	29.6	26.4	32.7	33.2
Sprowston ..	25.3	30.6	28.3	29.5	20.6	23.3	24.7	27.8
Plumpton ..	—	—	35.2	28.2	47.2	39.4	39.4[3]	33.6[3]
Wye	10.8[4]	—	47.8	41.5	15.2[5]	24.2	—	—
Long Sutton ..	27.6	29.3	—	—	10.8	—	—	—
Mean[1]	28.4[2]	31.6[2]	34.6	33.5	33.0	30.9	—	—

(1) Excluding Wye and Long Sutton.
(2) Adjusted to be comparable (over the same group of places) with the means of the other years, which include Plumpton.
(3) Adjusted to be comparable (over the same set of years) with the means of the other stations.
(4) Serious damage by birds.
(5) Damaged by Take-all (*Ophiobolus graminis* Sacc).

The association between shoot-height at ear emergence, plant number at tillering and yield of grain, enables a formula for the prediction of yield to be calculated. Working with the mean of the two standard varieties, and the first six stations of the accompanying table, it was found that for every increase of an inch in height (measured to the top of the sheath of the youngest leaf) an increase in yield of 1.32 cwt. per acre is to be expected, and that for every increase in plant number of 1 per foot-length of row, there is a decrease in yield of 0.62 cwt. With a height of 30 inches and a plant number of 10 per foot, the expected yield is 34.3 cwt. The values of the yields calculated from the formula are shown in the table for comparison with the actual yields.

These results are not sufficiently extensive to determine the accuracy of forecasts based on height measurements, but they suggest that simple measurements of this type may enable good forecasts to be made for any particular field.

Such forecasts, however, would be of little use in predicting the average yield of a district unless one knows how closely the yield on the observation plot is related to that of other fields in the same district.

The degree of association between fields in a district was estimated from samples taken by the crop weather observers in 1934 and 1935 from fields on different farms : the variability from field to field was remarkably high. In consequence both estimates and forecasts of the average yield of a district need to be based on observations of commercial crops.

The observations on wheat will be extended to study the possibilities of crop estimation at and prior to harvest. Suitable methods for sampling sugar beet and potatoes are being sought ; the Harper Adams College is co-operating in the sugar beet work.

DEPOSITS FROM THE ATMOSPHERE

Since 1915 Rothamsted has co-operated in the investigation of Atmospheric Pollution organized by the Department of Scientific and Industrial Research. Certain analyses of the rain and of the dust deposits are regularly made, and some of the results have now been summarised. (1) For the second year in succession our deposition gauge collected the smallest total solids out of the 98 gauges in use throughout the country. The total for the period April 1st, 1934, to March 31st, 1935, was made up as follows :

		Kg. per hectare	Cwt. per acre
Insoluble Matter	Loss on Ignition	59.4	0.473
	Ash	88.1	0.702
Soluble Matter	Loss on Ignition	93.9	0.748
	Ash	91.1	0.725
Total		332.5	2.648

The total deposit for the present year is the lowest since 1925-26 when a total of 307.5 kg per hectare (2.45 cwt. per acre) was collected. The average total for the last ten years is 401.1 kg per hectare (3.20 cwt. per acre) and the highest, recorded in 1929-30, was 507.4 kg. per hectare (4.04 cwt. per acre). The well-known positive correlation between rainfall and deposition of soluble matter is clearly apparent, and in consequence of this no secular change either for better or worse is detectable with certainty over this period.

The average monthly deposit was greater during the summer than the winter. This is a regular feature of our records, but it is particularly interesting this year, because rainfall had the opposite distribution.

	April to Sept.	Oct. to March
Average Monthly Rainfall, mm.	43	51
Average Monthly Deposition, Kg/hectare	31.8	23.6

(1) B. H. Wilsdon.—" Results of a statistical examination of records of deposit gauges." Appendix to Dept. Sci. Ind. Res., Twenty-first Report on Observations in the Year ended 31st March, 1935.

The recent analysis undertaken by B. H. Wilsdon shows that in London the rate of deposition of soluble matter is less in summer than in winter. This may be partly due to a lower rate of production: but taken in conjunction with the Rothamsted results, may indicate that summer conditions favour the transport of this fraction into the surrounding country. The seasonal distribution indicates that little of what we collect originates in the domestic fires of the neighbourhood, which are much more active in winter.

The fact that only 27 per cent. of the deposit at Rothamsted is non-combustible and insoluble in water shows that very little can be ascribed to dust from neighbouring fields and roads. Most of it comes from other sources.

At some of the other centres much higher values were obtained; near the Liverpool Docks, for instance, the atmospheric deposit amounts to almost one ton per acre per annum as against our 2½ cwt. Here also, as at Rothamsted, about half the soluble material and about one-third of the insoluble material is combustible: the difference in the amounts of these deposits appears to be much greater than the difference in their composition.

FARM HUSBANDRY INVESTIGATIONS

The investigations outlined above necessitate a considerable amount of field work which is carried out on the farm but this does not occupy anything like the whole of the land available. The classical fields are of course given up to their own crops, but all the newer experiments are made on the non-classical fields. Only certain areas, however, are suitable and the land available in any year is further restricted by the wholesome rule, to which we adhere closely, that an area of land once used for an experiment should not come again into experiment until after the lapse of three years. There is thus a considerable area of land to be farmed on ordinary commercial lines, besides numbers of live-stock needed for the consumption of the farm produce or for the testing of the value of the various fodder crops. Numerous opportunities arise for carrying out farm husbandry investigations by the farm manager and the farm recorder acting in conjunction with other members of the staff. These investigations are not connected with the main programme, but they are in all cases of considerable agricultural importance. Those at present in hand are set out below.

1. A comparison of electrical power with the tractor or stationary oil engine for the performance of work about the farm buildings.

This is being done under the aegis of the Royal Agricultural Society and it consists in finding the equivalence between units of electricity and gallons of paraffin for the various operations, account being taken of such details as starting and stopping. The results are expressed in terms of power consumed per ton of material threshed, ground, etc. In all cases the work is to be done in the ordinary farm way using ordinary farm labour; the results are to show what happens on good but ordinary farm conditions. They were discussed at a Conference held at Rothamsted in February, 1936, the report of which is now issued (p. 13).

2. The Production of Lamb. A breeding flock of 200 " Half-bred " ewes is maintained for ordinary farm use, and on this experiments are made :

(a) to test the effects of flushing ;
(b) to compare four-teated ewes with two-teated ewes as mothers ;
(c) to discover whether it is really necessary to import continuously new stock from the North or whether the breeding ewes can be produced here ;
(d) to study the advantages and disadvantages of breeding from ewes in their first year.

3. The Production of bacon. Some 20 breeding sows are kept and the progeny sold mostly for bacon.

Among the problems studied have been :

(a) the relative values of wet and dry feeding ; of restricted and unlimited feeding ;
(b) the value of green food ;
(c) the effect of the state of division of the food ;
(d) the effect of exercising the animals on the quality of bacon they yield.

THE DISSEMINATION OF THE RESULTS

This is one of the most difficult problems in connection with research work and it has no simple solution.

Several methods are adopted at Rothamsted :

1. The scientific papers are published in the appropriate journals and periodically collected as Volumes of Memoirs. At suitable times a monograph is published in which the various scattered papers dealing with a particular subject are combined and the necessary connecting and rounding-off experiments are made so as to give a coherent account of its present position. Seven of these have already been published dealing with Soil Fertility (the Director) ; Physical Properties of the Soil (Dr. Keen) ; Soil Micro-organisms (a joint production) ; Experiments on Grassland (Dr. Brenchley) ; British Aphides (Dr. Davidson) ; Soil Microbiology (Mr. Cutler and Miss Crump) ; the Woburn Field Experiments (the Director, Dr. J. A. Voelcker, with a Statistical Report by W. G. Cochran). The Director's Monograph on Soil Conditions and Plant Growth has passed through six editions and a seventh is in preparation ; it has been translated into French, German, Spanish, Russian and Ukrainian and pirated in China by photographic reproduction, omitting the name of the publisher but inadvertently including that of the printer. Other of the Director's books have been translated into Portuguese, Italian and Armenian and negotiations have been made for translation into Japanese, Hungarian and other languages. Dr. Keen's monograph on the Physical Properties of the Soil has been translated into Russian and Dr. Brenchley's monograph on grassland into German.

2. The practical and technical information is disseminated in three ways :

(a) by Conferences at Rothamsted at which practical men are invited to give their experiences and the Rothamsted staff and other experts also read papers. The proceedings are then published cheaply as booklets.

(*b*) by lectures to farmers' organisations This falls largely on Mr Garner, but the senior members of the staff including the Director regularly give a certain number. Field demonstrations are arranged at outside centres wherever the experimental results are suitable: this is usually done by Mr. Garner or Dr. Crowther, in association wherever practicable, with the County Organiser. Articles for the technical press are frequently written.

(*c*) by demonstrations at the Rothamsted Farm, usually by Mr. Garner, Captain Gregory and Mr. Moffatt. The numerous visitors to the laboratories are dealt with by Messrs. Garner and Gregory and a group of rota guides, which includes selected voluntary workers and all members of the scientific staff other than Heads of Departments. The number of visitors increases every year.

In addition there is a fair amount of visiting of farms when the owner not infrequently brings together a little group of neighbours for discussion.

THIRTY YEARS' WORK IN THE BOTANICAL DEPARTMENT. 1906-1936.

WINIFRED E. BRENCHLEY, D.Sc.

During the early years of Rothamsted the laboratory work was entirely concerned with matters arising from the field plots, chiefly chemical in nature, and this was carried on by a chemist and a few laboratory assistants under Sir Henry Gilbert. No regular botanist was needed, but when occasion arose a trained man was engaged temporarily to supervise the botanical separation of Park-grass Hay, this work being carried on later by Mr. J. J. Willis. By 1906 the scientific work of the institution was widened, and sub-division into departments gradually became necessary. The James Mason laboratory, erected in that year, served to house the various young biological departments until the general extension of the laboratories began about 1912. During that period the foundations of a botanical department were laid down, and the work was ready for fuller development when increased accommodation and working facilities became available.

In the early days of this century the question of the "strength" of wheat was receiving much attention, and the first problem dealt with in the new department was the possibility of associating the varying strength of wheat with cytological differences in the developing grain, but no such differences could be detected (1). Analyses made at three day intervals from flowering to maturity showed that at each stage the endosperm is filled by uniform material, possessing always the same ratio of nitrogenous to non-nitrogenous material and ash, this ratio being determined by such factors as variety, soil and season (2). With barley, as with wheat,

(1) W. E. Brenchley—" On the Strength and Development of the Grain of Wheat (Triticum vulgare). Ann. Bot., 1909. Vol. XXIII, pp. 117-39.

(2) W. E. Brenchley and A. D. Hall—" The Development of the Grain of Wheat." J. Agric. Sci., 1909. Vol. III, pp. 195-217.

the weight of the whole plant increases steadily until desiccation sets in, after which it falls ; the fall is greater for barley, which is cut dead ripe, than for wheat, which is cut when maturation changes are only beginning. With wheat from Broadbalk the manuring had very little effect on the composition of the grain or straw, whereas with barley from Hoos Field the effect of phosphoric acid starvation was reflected in the results obtained.(3). Later work on the phosphate requirements of barley emphasized the great importance of adequate supplies in the early stages of growth. Normal development and maximum dry weight are attained if phosphate is supplied for the first few weeks even if it be entirely withheld afterwards, though the actual amount of phosphate absorbed continues to increase steadily if the supply is maintained. On the other hand the absence of phosphate during early growth seriously hinders development, even though an adequate amount is given after short periods of deprivation. (4). Parallel experiments, as yet unpublished, indicate a somewhat similar response with regard to potash, maximum dry weight being attainable after a few weeks' initial supply, but with nitrogen, increase of dry weight continues with nitrogen supply up to a relatively short time before maturity.

The first work on plant physiology at Rothamsted was concerned with the action of various substances, especially plant poisons, on growth. It had been supposed that all substances deleterious to plant growth act as stimulating agents if they are available only in exceedingly minute quantities, and in 1907 investigations were begun in water cultures to test this hypothesis. Salts of manganese, copper, zinc, arsenic and boron were studied, but, while toxic effects were always produced by relatively small amounts, minute traces did not always have a stimulating action under the conditions of experiment. Arsenious acid and arsenites were far more toxic than corresponding doses of arsenic acid and arsenates. (5).

Boron is less toxic than the other elements tested, but it was not till 1921 that a chance observation drew attention to a far more important question—the possibility that boron might be an essential element for plant growth. Attempts to grow beans in water cultures had always failed, and it so happened that they had never been tested in solutions containing boron till 1921, when a series of *Vicia faba* plants were grown for entomological purposes with various elements in addition to the usual nutrient salts. This was followed up by Miss K. Warington, and it was conclusively established that a trace of boron is absolutely essential for the growth of many plants, and that in its absence the meristematic tissues are adversely affected and death ultimately occurs. In *Vicia* the cambium cells are greatly enlarged in the absence of boron, and breaking down of the vascular tissues proceeds from the stem apex downwards.

(3) W. E. Brenchley—" The Development of the Grain of Barley." Ann. Bot. 1912. Vol. XXVI., pp. 903-28 ; W. E. Brenchley—" The Development of the Flower and Grain of Barley." J. Inst. Brew. 1920. Vol. XXVI, pp. 615-32.

(4) W. E. Brenchley—" The Phosphate Requirement of Barley at Different Periods of Growth." Ann. Bot. 1929. Vol. XLIII, pp. 89-110.

(5) W. E. Brenchley—" The Influence of Copper Sulphate and Manganese Sulphate upon the Growth of Barley." Ann. Bot., 1910. Vol. XXIV, pp. 571-83 ; W. E. Brenchley—" On the Action of Certain Compounds of Zinc, Arsenic, and Boron on the Growth of Plants." Ann Bot. 1914 Vol. XXVIII, pp. 283-301 ; W. E. Brenchley—" Inorganic Plant Poisons and Stimulants" (Cambridge Univ. Press), Second Edition, 1927, pp. 134.

Deficiency of boron also adversely affects nodule production by inhibiting the development of the vascular strands which supply the carbohydrate material needed as a source of energy for the bacteria. The latter become parasitic, attacking the protoplasm of the host cell, and the ultimate result is abnormal nodules which are only capable of fixing very small amounts of nitrogen, less than one-tenth of that fixed in normal plants.

The need for boron was at first thought to be specific to leguminous plants, but it has since been shown to be essential for other species, although the requisite amount may be less. The chemical combination in which it is presented to the plant is immaterial, but no other element, out of over fifty tested, has proved capable of replacing it. Boron deficiency symptoms appear more slowly during spring and autumn than in the summer months, the delay being controlled more by the shorter length of day than by the lower temperatures. The symptoms are similar under both long and short day conditions, though they are less pronounced and their progress is retarded with short days. In no circumstances, however, did shortening the day when boron was supplied produce degeneration effects similar to those induced by a lack of boron. ([6]). Though the need for boron is fully recognised, its function is still undetermined. It may be connected with the uptake or utilisation of other nutrients, but though some indications were obtained of an association between boron and calcium, the evidence was not conclusive and the search continues.

This question of boron deficiency is proving to be one of considerable economic importance, as it is now found that certain obscure "physiological" diseases of important cultivated crops, *e.g.*, heart-rot of sugar beet, brown heart of turnips and certain tobacco diseases, can be cured by the application of from 12-20 lb. of borax per acre. In Sumatra boron compounds take a regular place in the manuring of the tobacco crops, and wherever sugar beet is grown watch is being kept for heart-rot and boron amelioration is being attempted. The subject is being further studied. ([7]).

During recent years much attention has been directed to the importance of these "minor" elements in plant nutrition, and to the possibility of utilising them in agricultural practice for crop improvement. Before this can be done, however, full information on the action of the various elements is needed, and the botanical department endeavours to supply this. Claims are frequently made of heavy crop increases due to the use of certain elements, such as titanium, copper, etc., and these are as far as possible investigated both in soil and water cultures. It seldom happens that the benefit

(6) K. Warington—"The Effect of Boric Acid and Borax on the Broad Bean and certain other Plants." Ann. Bot., 1923, Vol. XXXVII, pp. 629-72 ; K. Warington—"The Changes induced in the Anatomical Structure of *Vicia faba* by the Absence of Boron from the Nutrient Solution." Ann. Bot., 1926, Vol. XL, pp. 27-42 ; W. E. Brenchley and H. G. Thornton—"The Relation between the Development, Structure and Functioning of the Nodules on *Vicia faba*, as influenced by the Presence or Absence of Boron in the Nutrient Medium." Proc. Roy. Soc. B., 1925, Vol. 98, pp. 373-99 ; W. E. Brenchley and K. Warington—"The Rôle of Boron in the Growth of Plants." Ann. Bot., 1927, Vol.XLI, pp. 167-87 ; K. Warington—"The Influence of Length of Day on the Response of Plants to Boron." Ann. Bot., 1933, Vol. XLVII, pp. 429-57.

(7) K. Warington—"Studies in the Absorption of Calcium from Nutrient Solutions, with Special Reference to the Presence or Absence of Boron." Ann. Bot., 1934, Vol. XLVIII, pp 743-76 ; E. Rowe—"A Study of Heart-rot in young sugar beet plants grown in culture solutions." Ann. Bot. (In press).

claimed can be substantiated under experimental conditions, but the possibility always exists, and it is of the greatest importance that all available information shall be obtained on the action of various elements on different types of soil and under different growth conditions.[8].

From time to time an agricultural outlet is sought for by-products in industry. Attempts were made to use iodine compounds (of which there are considerable potential supplies) as a partial sterilisation agent to improve the germination of tomatoes in " sick " soils, and as a preventive of " damping off," but with little or no success. Stronger doses of iodine added to the usual manures were definitely harmful to the germination of barley and mustard, if the seeds were sown directly after treatment. This toxic action gradually decreased and later sown seeds were not affected. Although occasional examples of stimulation were observed in mustard, the results failed to justify any recommendation of an extended use of iodine for agricultural purposes. [9].

The large percentages of silicon present in certain crops, especially cereals, had long attracted attention and suggested that silicon could partially replace phosphorus in the economy of the plant. Experiments in water cultures indicated that under normal conditions of nutrition, with available phosphate present, silicon is ineffective in improving growth, though in the entire absence of phosphate it may produce a slight increase in dry weight. Crops vary in their response to silicate on different types of soil, a certain improvement being obtained chiefly when potash or phosphate is deficient. The benefits, however, were insufficient to justify the addition of silicates to the usual manures.[10]

The action of certain organic compounds on growth has been studied in view of their use as fumigants or sterilising agents. When supplied through the roots, prussic acid and cyanides are extremely poisonous ; 1 part in 100,000 proved fatal to peas, and barley was slightly more resistant, but no sign of stimulation has been observed with any concentration down to 1 part in 1,000,000,000. The phenols behave similarly in their general effects, though the individual substances exert their specific action at somewhat different concentrations. High concentrations are fatal, and somewhat lower strengths have a paralysing effect at first, seriously checking growth for some time. This inhibition gradually wears off, and the affected plants may ultimately make as good growth as the controls. This type of temporary inhibition is rarely seen with inorganic poisons, and may be due to a weakening of the organic toxic material by oxidation or other chemical change. [11]

---

(8) W. E. Brenchley—" The Action on the Growth of Crops of Small Percentages of certain Metallic Compounds when applied with Ordinary Artificial Fertilisers." J. Agric. Sci., 1932, Vol. XXII, pp. 705-35 ; W. E. Brenchley—" The Effect of Rubidium Sulphate and Palladium Cloride on the Growth of Plants." Ann. Appl. Biol., 1934, Vol. XXI, pp. 398-417 ; W. E. Brenchley —" The Essential Nature of certain Minor Elements for Plant Nutrition." Bot. Rev., 1935. Unpublished work on Copper, Nickel and Cobalt.

(9) W. E. Brenchley—" The Effect of Iodine on Soils and Plants." Ann. Appl. Biol., 1924, Vol. XI, pp. 86-111.

(10) W. E. Brenchley, E. J. Maskell and K. Warington—" The Inter-relation between Silicon and other Elements in Plant Nutrition." Ann. Appl. Biol., 1927, Vol. XIV, pp. 45-82.

(11) W. E. Brenchley—" Organic Plant Poisons. I. Hydrocyanic Acid." Ann. Bot., 1917 Vol. XXXI, pp. 447-56 ; W. E. Brenchley—" Organic Plant Poisons. II. Phenols." Ann. Bot. 1918, Vol. XXXII, pp. 259-78.

Alcohol, absorbed by the roots, is definitely toxic in fairly high concentrations, ethyl alcohol being more poisonous to barley than methyl alcohol. The difference in toxicity is not merely one of degree, but of kind, as with ethyl alcohol ear development was found to begin early, with a corresponding early death of superfluous leaves, whereas with methyl alcohol active vegetative growth continued much longer and ear development was delayed. ([12]). A general review of the resistance of plants to poisons and alkalies, covering a wide field, was recently presented at the Third International Congress for Comparative Pathology at Athens. ([13])

During the course of these inquiries various physiological problems arising out of the methods of technique were studied. Early work with solutions extracted from various Rothamsted soils indicated that within wide limits the rate of growth of a plant varies with the concentration of the nutritive solution, irrespective of the total amount of plant food available. Later on, in standardising the solutions to be used for water cultures, it was again found that the concentration of the nutrient solution, up to a comparatively high strength, has a great effect upon the rate and amount of growth and that starvation effects, due to insufficient nutriment, are obtainable in much stronger concentrations than was usually recognised. ([14])

The harmful effect of overcrowding plants is usually attributed to competition for food and water in a limited area of soil. The importance of aerial competition for light, essential for photosynthesis, was shown by growing barley plants in individual bottles to eliminate competition for food and water, but so closely crowded together that serious shading occurred. The crowded plants suffered drastic reduction in development and ear production, whereas corresponding plants, given ample space, tended to produce a standard type in which the relation between the number of tillers and ears, dry weights, and ratios of root to shoot approximated in some degree to a constant standard.

Although the water culture work is carried on in a roof greenhouse, with minimum interference with the available light, the effective experimental period during the year is limited by light conditions, and as a general rule, few experiments can be carried on during the winter months. On the other hand, cereals fail to grow well if sown too late, and the usual plan is to start cereal experiments during February or March at the latest, and when a later crop is required to utilise other plants, as broad beans or peas, which will develop successfully from summer sowings. Depression of growth during very hot sunny weather was traced to high temperatures at the roots associated with strong and prolonged sunshine, though the two factors acting individually cause much less

(12) A. N. Puri—" Effect of Methyl and Ethyl Alcohol on the Growth of Barley Plants." Ann. Bot., 1924, Vol. XXXVIII, pp. 745-52.

(13) W. E. Brenchley—" The Resistance of Plants to Poisons and Alkalies." Rapp. 3rd Inter. Cong. Pathol. Comp., Athens, 1936, pp. 3-23.

(14) A. D. Hall, W. E. Brenchley and L. M. Underwood—" The Soil Solution and the Minera Constituents of the Soil." J. Agric. Sci., 1914, Vol. VI, pp. 278-301 ; Phil. Trans. Roy. Soc. B., 1914, Vol. 204, pp. 179-200 ; W. E. Brenchley—" The Effect of the Concentration of the Nutrient Solution on the Growth of Barley and Wheat in Water Cultures." Ann. Bot., 1916, Vol. XXX, pp. 77-90.

damage. This difficulty was overcome by using sun-blinds and by giving better protection from the direct rays of the sun to the culture bottles, thus keeping the root temperatures at a lower level.([15]).

In pot and water culture experiments the ultimate measure of the result is usually that of dry weight, associated with chemical analyses and observations made during growth. The practice has always been to grade the larger seeds used for experiment within close limits of weight, on the assumption that the amount of reserve food in the seed might have an effect upon growth and the final crop. The correctness of this assumption was proved by experiments with peas and barley in which a steady and considerable rise in the dry weight of the plants occurred as the initial weight of the seed increased. Similar results were obtained with either a limited or abundant food supply, and justify the use of large heavy seed for agricultural crops.

With pot cultures the caking of the soil due to surface watering has been overcome by sinking small earthenware pots to their rims in the soil of the experimental pots, and adding the water through the porous pots. Better root development is thus obtained and incidentally much time is saved in watering. ([16])

Much of the work of the botanical department is concerned with germination and pot culture tests of manures and other substances requiring investigation, the results of which are frequently incorporated in unpublished reports. With the outbreak of the Great War, fertilisers became increasingly difficult to obtain, and various waste products were examined in the search for substitutes, such as pottery waste, leather waste, flue dust and blast furnace dust containing lead oxide. The conclusion of the War brought a reversal of activities in the attempt to find an outlet for superfluous munitions by converting T.N.T., cordite, etc., into fertilisers and utilising ammonium and potassium perchlorates as weed-killers, as they are too toxic to have manurial value. Germination tests are repeatedly called for, often as a preliminary to further developments if the results prove satisfactory. Large scale pot culture experiments may be carried on for several years before the final report is issued, and frequently a number of soils are imported from various districts in order that tests may be made on different soils under parallel environmental conditions. Superphosphate, mineral phosphate, basic slag, ammonium humate, cyanamide, humunit, sewage sludge, poultry manure, copper sulphate and peat manure are among the substances investigated over a long period, in some cases in association with the chemical department.([17])

The root development of barley and wheat was worked out with

---

(15) W. E. Brenchley—"Some Factors in Plant Competition." Ann. Appl. Biol., 1919, Vol. VI, pp. 142-70; W. E. Brenchley—"On the Relations between Growth and the Environmental Conditions of Temperature and Bright Sunshine." Ann. Appl. Biol., 1920, Vol. VI, pp. 211-44; W. E. Brenchley and K. Singh—"Effect of High Root Temperature and Excessive Insolation upon Growth." Ann. Appl. Biol., 1922, Vol. IX, pp. 197-209.

(16) W. E. Brenchley—"Effect of Weight of Seed upon the Resulting Crop." Ann. Appl. Biol., 1923, Vol. X, pp. 223-40; K. Singh—"Development of Root System of Wheat in different kinds of soils and with different methods of Watering." Ann. Bot., 1922, Vol. XXXVI, pp. 353-60.

(17) W. E. Brenchley and E. H. Richards—"The Fertilising Value of Sewage Sludges." J. Soc. Chem. Ind., 1920, Vol. XXXIX, pp. 177-82; E. M. Crowther and W. E. Brenchley. "The Fertilising Value and Nitrifiability of Humic Materials prepared from Coal." J. Agric. Sci., 1934, Vol. XXIV, pp. 156-76.

special reference to the "white" roots produced about the time that tillering begins. Their function is probably to provide the plant with a plentiful supply of water and dissolved nutrients at the time that vigorous growth is setting in, abundant root hairs and an enlarged conducting system forming the necessary mechanism.([18])

A further branch of the department's activities deals directly with field problems. The important question of weeds and their eradication led to a series of surveys of arable land to ascertain how far weed species are associated with particular soils or crops, and to what extent they are of general distribution. Comparatively few individual weeds can be regarded as symptomatic of special types of soils, but groups of weeds are characteristic of clay, chalk and peat while loams tend to be colonised by a greater variety. Information on these points is still being collected with the aid of observers in schools and colleges in various parts of the country.([19])

The harmful effect of weeds in crops appears to be due to direct competition for the essential food, water and light, though the possibility of some toxic effect by root excretions cannot altogether be ruled out. Accurate knowledge of the habits of weeds is essential for devising appropriate methods of eradication, and a considerable amount of work has been devoted to this end.([20])

Direct experiments on eradication have been carried out from time to time, the most noteworthy results being the effective use of perchlorate for ridding paths of weeds, and the possibility of utilising thiocyanates for improving very weedy grassland. The latter experiment is still in hand, and promises considerable success. Sodium chlorate is so effective in keeping down weeds that it is now regularly used in the precincts of the laboratories. Special care is needed to avoid splashing boots and clothes with the solution as chlorates are very inflammable if they dry on to organic material.

The difficulties of weed eradication are intensified by the fact that seeds buried in the soil are able to retain their vitality for long periods, often extending over many years. Living seeds of weeds characteristic of arable land were found in areas that had been under grass for varying times (Laboratory House Meadow, 58 years; Barnfield grass, 40 years; Geescroft, 32 years, New Zealand field, 10 years). More than a dozen species germinated, *Atriplex patula* and *Polygonum aviculare* providing the greatest number of

---

(18) W. E. Brenchley and V. G. Jackson—"Root Development in Barley and Wheat under different conditions of Growth." Ann. Bot., 1921, Vol. XXXV, pp. 533-56; V. G. Jackson—"Anatomical Structure of the Roots of Barley." Ann. Bot., 1922, Vol. XXXVI, pp. 21-39.

(19) W. E. Brenchley—"The Weeds of Arable Land in Relation to the Soils on which they Grow." I. Ann. Bot., 1911, Vol. XXV, pp. 155-85; "The Weeds of Arable Land in Relation to the Soils on which they Grow." II. Ann. Bot., 1912, Vol. XXVI, pp. 95-109; "The Weeds of Arable Land in Relation to the Soils on which they Grow." III. Ann. Bot., 1913, Vol. XXVII, pp. 141-66; W. E. Brenchley—"Weeds in Relation to Soil." J. Bd. Agric., 1911-12, Vol. XVIII, pp. 18-24; J. Bd. Agric., 1912-13, Vol. XIX, pp. 20-26; J. Bd. Agric., 1913-14, Vol. XX, pp. 198-205; W. E. Brenchley—"Weeds of Farm Land." Longmans, Green & Co., 1920, pp. 239; W. E. Brenchley—"Yellow Rattle as a Weed on Arable Land." J. Bd. Agric., 1912-13, Vol. XIX, pp. 1005-9.

(20) W. E. Brenchley—"The Effect of Weeds upon Cereal Crops." New Phyt., 1917, Vol. XVI, pp. 53-76 W. E. Brenchley—"The Effect of Weeds upon Crop." J. Bd. Agric., 1917-18, Vol. XXIV, pp. 1394-1400; W. E. Brenchley—"Weeds on Arable Land and their Suppression." J. Roy. Agric. Soc. Eng., 1915, Vol. LXXVI pp. 1-24; W. E. Brenchley—"Spraying for Weed Eradication" J Bath and West & Sou. Coun. Soc., 1924-25, Vol. XIX, pp. 1-20; W. E. Brenchley—"Eradication of Weeds by Sprays and Manures." J. Bd. Agric., 1918-19, Vol. XXV, pp. 1474-82; W. E. Brenchley—"West Country Grasslands." J. Bath and West & Sou. Coun. Soc., 1916-17, Vol. XI, pp. 1-28.

https://doi.org/10.23637/ERADOC-1-67

individuals.[21] The undue increase of poppies and black bent (*Alopecurus agrestis*) on Broadbalk field led to a two-year fallow, providing opportunity for making a numerical census of the number of viable seeds in the soil before and during treatment, and of following up the after effects of fallowing on the weed flora. Weed species in general show a definite tendency to germinate at a particular season: the majority germinate chiefly in the autumn, but a few, e.g. *Polygonum aviculare* and *Bartsia odontites*, reach their maximum in the spring. This is of great importance in practice, as weeds are most easily destroyed in the seedling stage, and cultivation during the dormant period of the seeds can do nothing towards their eradication. No adequate explanation of the cause of this seasonal effect is forthcoming, though experiments carried out with seeds kept in constant and in fluctuating daily temperatures indicate that temperature conditions are apparently of great, though not of sole, importance. Fallowing operations do not equally reduce all species, as the range of reduction varies over a wide percentage, while a few species may even be increased. This occurs if the interval between cultivations is too long, as some rapidly-growing species are then able to reach maturity and replenish the soil with seeds. The ultimate re-establishment of weed species is not correlated with the degree of reduction by fallowing, but seems to depend upon the rapidity with which any species can begin to reassert itself. *Alopecurus agrestis* and *Stellaria media* were drastically reduced by fallowing, but within three years they were more plentiful than before treatment, whereas *Papaver rhœas* has remained approximately at the fifty per cent. level to which it was reduced by the fallow.[22]

The results of giving weeds a free hand among the crops is well shown by Broadbalk wilderness, in which the wheat crop of 1882 has reverted to an oak-hazel wood where it is entirely undisturbed, and to a rough meadow where the trees and shrubs are removed yearly.[23]

The dominant species in the weed flora of any area are to a great extent determined by the crop and its type of cultivation, winter wheat, spring barley and root crops presenting quite a different balance in their associated weeds. The cumulative effect of long-continued manuring appears to be of secondary importance except in cases of serious deficiency, such as a lack of nitrogen or exhaustion of minerals induced by a prolonged application of ammonium salts only.[24]

Though weeds are generally regarded as pernicious, they have certain beneficent aspects, and during the War search was made for the various uses to which they could be put as substitutes for essential materials that were difficult to obtain. The range of

---

(21) W. E. Brenchley—"Buried Weed Seeds." J. Agric. Sci., 1918, Vol. IX, pp. 1-31.

(22) W. E. Brenchley and K. Warington—"The Weed Seed Population of Arable Soil. I." "Numerical Estimation of Viable Seeds and Observations on their Natural Dormancy." J. Ecol. 1930, Vol. XVIII, pp. 235-72; II. "Influence of Crop, Soil and Methods of Cultivation upon the Relative Abundance of Viable Seeds." J. Ecol., 1933, Vol. XXI, pp. 103-27; III. "The Re-establishment of Weed Species after Reduction by Fallowing." J. Ecol. (In Press); K. Warington—"The Effect of Constant and Fluctuating Temperature on the Germination of the Weed Seeds, in Arable Soil." J. Ecol., 1936, Vol. XXIV, pp. 185-204.

(23) W. E. Brenchley and H. Adam—"Re-colonisation of Cultivated Land allowed to revert to Natural Conditions." J. Ecol., 1915, Vol. III, pp. 193-210.

(24) K. Warington—"The Influence of Manuring on the Weed Flora of Arable Land." J. Ecol., 1924, Vol. XII, pp. 111-26.

possible uses is very wide, but in most cases the value is too low or the costs of collection and manufacture are too great for economic exploitation under normal conditions.[25]

Through all these years of change and progress the original botanical work on Park grass was never neglected. Partial analyses of the herbage were made year by year, by Mr. J. J. Willis, till his death in 1911, after which the work was transferred to the botanical department. In 1914 and 1919 complete botanical analyses of every plot were made by a specially recruited staff of assistants, with Miss G. Bassil as deputy supervisor and Mr. E. Gray as referee for knotty points, in view of his long experience of the plots and methods of separation. These results provided a gauge for estimating the change in the herbage since 1877, when Lawes, Gilbert and Masters had completed a series of four quinquennial analyses. They also demonstrated the effects of the system of liming one half of each plot, instituted by Mr. (now Sir) A. D. Hall, in 1903. Complete and partial analyses of specific plots are still made regularly, and a complete synopsis of the results obtained since the experiment was started in 1856 is now available in published form.[26] The serious lodging that occurs on the heavily-manured plots in some seasons and the comparative rigidity of plants supplied with potassium salts led to an anatomical investigation of *Dactylis glomerata*, and the results seemed to point to the rigidity being due to physiological causes rather than to anatomical strengthening.[27] At one period, when frost had devastated the unlimed area receiving heavy dressings of ammonium sulphate, a heavy invasion of fireweed (*Epilobium angustifolium*) occurred, but in succeeding years it failed to hold its ground, and disappeared from the plots.[28]

On the solitary classical plot (Plot 13) receiving organic manures, liming usually proved detrimental to the crop. From 1920 other plots were treated with light and heavy dressings of lime at four-year intervals, and again it appeared that in conjunction with organic manure, or with such combinations of artificials as nitrate of soda and minerals, liming may cause considerable reduction of yield.[29]

The present practice with regard to Park grass is to conduct botanical analyses over a period of years to elucidate some special point in connection with the effect of certain manurial systems. From 1919 to 1934 attention was concentrated on the influence of season upon the botanical composition of the herbage from year to year, in the presence and absence of lime. With complete fertilisers,

(25) W. E. Brenchley—" Useful Farm Weeds." J. Min. Agric., 1918-19, Vol. XXV, pp. 949-58; W. E. Brenchley—" Uses of Weeds and Wild Plants." Sci. Prog., 1919, Vol. XIV, pp. 121-33; W. E. Brenchley—" Weeds of Farm Land." Longmans, Green & Co., 1920, pp. 187-205.

(26) J. B. Lawes, J. H. Gilbert and M. T. Masters—" Results of Experiments on the Mixed Herbage of Permanent Meadow. II. The Botanical Results." Phil. Trans. Roy. Soc., Part IV, 1882, pp. 1181-1413; W. E. Brenchley—" Manuring of Grass Land for Hay." Longmans, Green & Co., 1924, pp. 146; W. E. Brenchley—" Park Grass Plots." Rothamsted Annual Rep., 1934, pp. 138-159.

(27) O. N. Purvis—" The Effect of Potassium Salts on the Anatomy of *Dactylis glomerata*." J. Agric. Sci., 1919, Vol. IX, pp. 338-65.

(28) W. E. Brenchley and S. G. Heintze—" Colonisation by *Epilobium angustifolium*." J. Ecol., 1933, Vol. XXI, pp. 101-2.

(29) W. E. Brenchley—" Effect of Light and Heavy Dressings of Lime on Grassland." J. Bd. Agric., 1925-6, pp. 504-12; W. E. Brenchley—" The Varying Effect of Lime on Grassland with different Schemes of Manuring." J. Min. Agric., 1925, pp. 504-12.

including nitrogen and minerals, the relative proportions of the three main groups of species, i.e. grasses, leguminous and miscellaneous plants, are not usually much affected by season, though the individual species vary, but with one-sided fertilisers and on unmanured areas wide fluctuations occur in the percentage of these groups.[30] A new cycle of analyses is now being carried out to determine the effect of potash on the herbage fluctuations from year to year in relation to the supply of nitrogenous fertilisers. The Park grass plots afford a unique opportunity of observing the relations between plant species and seasonal and manurial conditions.

INSECT PESTS AT ROTHAMSTED AND WOBURN, 1935

A. C. Evans

General

A very severe attack of pigmy mangold beetle occurred on Barnfield, the entire crop being lost. Wheat bulb-fly caused much damage on the Alternate Wheat and Fallow and on the Four-Course Rotation experiments. Pigeons completely destroyed the first planting of brussels sprouts on Fosters.

Wheat

Wheat bulb-fly (*Hylemyia coarctata* Fall.) caused much damage on the Alternate Wheat and Fallow and Four Course Rotation experiments, but was slight elsewhere. On Broadbalk, the wheat blossom midges (*Sitodiplosis mosellana* Géhin and *Contarinia tritici* Kirby) are steadily increasing. The following are the figures for the last three years.

	Number of Larvae per 500 ears		
	1933	1934	1935
C. tritici	1,474	3,381	4,289
S. mosellana	319	572	4,221
	Percentage Grain Attack		
C. tritici	0.7	1.5	2.1
S. mosellana	1.4	2.5	18.0

The percentage parasitism found is still low, and so a still further increase in the numbers of the midges is expected in 1936.

Barley

Few gout-fly (*Chlorops taeniopus* Meig.) were present. Several arvæ of a leaf-eating beetle (*Lema melanopa L.*) were found on barley on Hoos field. This species has not yet been recorded in these reports as occurring on the farm.

Oats

A severe attack of eelworm (*Heterodera schachtii* Schmidt) occurred on Long Hoos I. Fortunately the infested area was small.

(30) W. E. Brenchley—" The Influence of Season and of the Application of Lime on the Botanical Composition of Grass Land Herbage." Ann. App. Biol., 1935, Vol. XXII, pp. 183-207.

Kale

Few cabbage aphis (*Brevicoryne brassicae* L.) were present on on this crop on Pastures, but large numbers of flea-beetles (*Phyllotreta* spp.) appeared towards the end of August. However, the plants were well developed and no appreciable damage was done.

Brussels sprouts

The first planting was entirely destroyed by wood-pigeons. Cabbage aphis was plentiful on some plants of the second planting, but a general infestation did not occur.

Sugar Beet

Pigmy mangold beetle (*Atomaria linearis* Steph.) and flea-beetles were present, but no damage was evident.

Beans

Bumble bees (short-tongued *Bombus* spp.) bit through the base of the bean flowers, one hundred per cent. being pierced in this way during June. A species of pollen-eating beetle (*Meligethes aeneus* F.) entered the flower through the hole, laid eggs and several larvæ were usually recovered later from each flower. During July the flowers were not bitten so frequently. It is thought that no damage resulted to the crop.

Mangolds

The crop of mangolds on Barnfield was destroyed by a very severe infestation of pigmy mangold beetle H. F. C. Newton recorded a general attack by this pest on this field during 1934, but in spite of this the resulting crop was better than the fifty-three year average. A survey of all treatments of strips 1, 2, 5, 7 and 8 was undertaken on June 11th. Two samples of soil 12 inches long by 3 inches wide by 3 inches deep were taken at random along the row in each plot. The plant was completely exterminated on the following plots : 1A, 2A, 1N, 2N and 5N, and no beetles at all were found on these plots The remaining plots showed great variation in the size of the plants and the numbers of beetles per sample. In general, the plants were smaller on the A, N and O strips, and larger on the AC and C strips. The concentration of the pest corresponded with the size of the plants. Mr. Newton recorded that in 1934 the beetle was fairly evenly distributed over the field. He took 100 samples and these yielded some 500 beetles. This year 50 samples were taken and these yielded well over 2,000 beetles, the largest number in one sample being 150. The writer only took up his duties on June 1st, and so only the later phases of the infestation were studied. The beetle population, at this late stage of the infestation, was definitely greatest on the rape cake area. In the rape cake area the population was highest on plots 7C and 7AC, lowest on plots 5C and 5AC, and intermediate on the other plots. The seed for the 1936 crop has been treated with a mixture of phenol and magnesium sulphate in an effort to combat the pest.

WOBURN

The farm at Woburn was visited on July 13th, but no serious insect damage was seen.

FUNGUS AND OTHER DISEASES AT ROTHAMSTED AND WOBURN, 1935

MARY D. GLYNNE

WHEAT

Three diseases which had not previously been recorded on wheat in this country were found at Rothamsted in 1935.* Of these, *Cercosporella herpotrichoides* Fron. is considered one of the most important of the fungi causing foot-rot of wheat in certain parts of France and of the United States and has recently been recorded in Germany, Holland and Denmark; *Gibellina cerealis* Pass. causes " white straw " disease in wheat and is found in Italy and has recently been recorded in Oregon. *Ophiobolus herpotrichus* (Fr.) Sacc. occurs in several European countries with other fungi causing foot-rot in wheat and is generally regarded as a weak parasite of secondary importance. It has been found on wild grasses, but not previously on cereals in Great Britain and America.

Cercosporella herpotrichoides Fron. was observed in February, causing pale lesions with dark borders on the outer sheaths and leaf bases in Broadbalk and in the adjacent Pennells Piece. Spores were produced abundantly in a few days in the laboratory on material collected in the latter part of March, but hardly any were found in material collected at intervals subsequently. The lesions on sheath and stem were observed till harvest and were abundant among plants which had lodged but were also present on many which had not lodged. The disease was moderate on all Broadbalk plots and on Pennells Piece and was also recorded in certain other fields at Rothamsted.

White Straw Disease (*Gibellina cerealis* Pass.) was found affecting about twenty scattered plants on Hoos alternate wheat and fallow plot. One plant was also found on an adjacent plot of the soil exhaustion experiment.

Ophiobolus herpotrichus (Fr.) Sacc. was found in March in Pennells Piece on wheat stubble which had overwintered in the soil, but no evidence of parasitism was obtained.

Mildew (*Erysiphe graminis* DC.) was noted in February, and by the end of April was unusually plentiful on the nitrogenous manure and Precision experiments on Great Harpenden field. In June and July it was mostly slight or moderate and occasionally plentiful.

Whiteheads (Take-all) (*Ophiobolus graminis* Sacc.). As in many other districts, this disease was unusually common at Rothamsted this year. In Broadbalk it was first noted in March, and by harvest was moderate on several plots, notably the unmanured and that which receives only mineral manure. In Hoos exhaustion experiment, in which manuring has been practically discontinued

* Glynne, Mary D.—" Some New British Records of Fungi on Wheat. *Cercosporella herpotrichoides*, Fron., *Gibellina cerealis* Pass., and *Ophiobolus herpotrichus* (Fr.) Sacc." Trans. Brit. Myc. Soc., 1935, XX, p. 120-122.

since 1901, it was particularly plentiful on those plots in which the previous manurial treatment would seem likely to leave the soil most exhausted. It was present but not plentiful, on a commercial crop grown in rotation on Long Hoos. At Woburn it was slight on the 6-Course rotation and moderate to plentiful on limed and unlimed plots of the alternate wheat and green manure experiment on Stackyard, an eye estimation of the latter suggesting that about 20 to 25 per cent. of the plants were affected. On Lansome, alternate wheat and green manure experiment, it was moderate with bad patches, particularly on the control, and on the old mustard plots which yielded very poor crops.

Loose Smut (*Ustilago Tritici* (Pers.) Rostr.) was very slight at Rothamsted and Woburn.

Yellow Rust (*Puccinia glumarum* (Schm.) Ekriss. and Henn.) was first noted in February and in March was moderate, and in some spots plentiful on the Precision wheat on Great Harpenden field, but in spite of its early appearance it did not seem more than usually abundant later in the season. It was slight to moderate on other wheat crops at Rothamsted, and rather less common at Woburn.

Brown Rust (*Puccinia triticina* Erikss.) was slight and occasionally moderate in incidence at Rothamsted, and slight at Woburn.

Foot Rot (*Fusarium* sp.) was occasional at Rothamsted and Woburn.

Leaf Spot (*Septoria Tritici* Desm.) was moderate at the end of January, causing leaf lesions in the alternate wheat and fallow crop on Hoos field and slight or absent in others. In March and April it varied from slight to moderate on other wheat crops at Rothamsted.

OATS

Mildew (*Erysiphe graminis* DC.) varied from slight to plentiful, being most abundant where growth was most luxuriant at Rothamsted.

Crown Rust (*Puccinia Lolii* Niels.) was slight on the commercial oats on Hoos field and moderate on the fumigation experiment on Pastures.

Leaf Spot (*Helminthosporium Avenae.* Eid.) was slight on both crops at Rothamsted. In November it was moderate on self-sown oats on Long Hoos field and was sporing freely. It was also found at the same time in a new crop of oats in the same field.

BARLEY

Mildew (*Erysiphe graminis* DC.) was moderate to plentiful in the late summer on most of the barley at Rothamsted, and was slight at Woburn.

Net Blotch (*Pyrenophora teres* Drechsl.) was only slight at Rothamsted and was not recorded at Woburn.

Brown Rust (*Puccinia anomala* Rostr.) was plentiful at Rothamsted in the late summer and was not recorded at Woburn.

Leaf Stripe (*Helminthosporium gramineum* Rabenh.) was slight in March on self-sown barley, but was not recorded elsewhere.

Leaf Blotch (*Rhynchosporium Secalis* (Oud.), Davis) which had not been found in 1933 or 1934, though fairly common in previous years, appeared this year in March and April on self-sown barley in a temporary rye grass ley on Hoos field. In the neighbouring continuous barley experiment the disease was fairly plentiful from June onwards, and in the adjacent nitrogenous manure experiment it was very abundant at the side nearest the temporary ley and slight at the opposite side. There was a distinct suggestion that the infection of these two crops may have been chiefly due to wind-borne spores from the self-sown barley in the temporary ley. In other barley crops at Rothamsted and on Stackyard at Woburn the disease was only slight.

RYE

Mildew (*Erysiphe graminis* DC.). A trace was noted on dead lower leaves in July at Rothamsted.

Brown Rust (*Puccinia secalina* Grove) was very slight in July at Rothamsted.

Leaf Blotch (*Rhynchosporium Secalis* (Oud.) Davis) was moderate to plentiful from May to July at Rothamsted. At the end of July it was found only on dead leaves.

GRASS PLOTS

Choke (*Epichloe typhina* (Fr.) Tul.) was a little less common on Agrostis than usual and was rare on Dactylis. This was possibly connected with the fact that 1935 was a " late season " and the stromata of the fungus may not have all been developed. As in previous years, the disease occurred most plentifully on the more acid plots, where also Agrostis was most common. Eggs and larvæ of the dipteron *Anthomyia spreta* Meig. were as usual found on the fungal stroma.

CLOVER

Downy Mildew (*Peronospora Trifoliorum* de Bary) was moderate in June and July at Woburn.

Rot (*Sclerotinia Trifoliorum* Erikss.) was rather plentiful in the winter of 1934 and early part of 1935 on Long Hoos 6-Course rotation and on Pastures field temporary ley. In both experiments bad patches were found on every plot. The disease was checked by frost in February, but patches in which the plants were dead or much damaged remained poor. The crop in Pastures made a better recovery than that in Long Hoos.

LUCERNE

Downy Mildew (*Peronospora Trifoliorum* de Bary) was slight at Woburn from May onwards.

BROAD BEAN

Chocolate Spot, characterised by lesions of limited area, is now regarded as due to *Botrytis* spp., which also causes lesions of unlimited area of the type previously recognised as *Botrytis* spp. Chocolate spot was first observed in the latter part of April on Little Hoos manuring experiment, and on Great Knott in a commercial crop. By the end of June it was plentiful on all plots of the manuring experiment and on the commercial crop, all except the young leaves being attacked. *Botrytis* spp. causing lesions unlimited in area varied in the manurial experiment from slight to moderate in plots which had received potash in the fertiliser either as potassium chloride or in dung, and from moderate to plentiful in plots which had received no potash ; potash deficiency thus appeared to result in a definite increase in the disease. The fungal attack increased, till by August 1st it was plentiful on all plots. The early attack would, however, be most likely to cause loss in crop. In Great Knott the disease was plentiful by the beginning of July, especially on the lower parts of the plants killing the older leaves and possibly causing considerable reduction in crop.

Rust (*Uromyces Fabae* (Pers.) de Bary) was slight on Little Hoos in mid-July and plentiful in all plots at the beginning of August. None was found on Great Knott in late July.

Aschochyta Fabae Speg. was found on the seeds of the crop from Little Hoos, and was fairly common in October on the leaves of self-sown plants in that field.

Potato

Virus. Mosaic was slight at Rothamsted and Leaf Curl slight at Rothamsted and Woburn. Streak was moderate at Woburn about 10 per cent. of the plants being affected on Lansome, and about 30 per cent. on Butt Furlong.

Late blight (*Phytophthora infestans* (Mont.) de Bary) was fairly common at Rothamsted at harvest.

Early blight (*Alternaria Solani* (E. and M.) Sorauer, emend. Jones and Grout) was plentiful at harvest on the green leaves producing black patches which produced spores in damp chambers.

Mangold

Leaf Scorch (?physiological) and a Virus Mosaic were moderate on Long Hoos continuous cultivation experiment in October.

Sugar Beet

Virus Mosaic was slight on Long Hoos 6-Course rotation experiment in October.

Crown Gall (*Bacterium tumefaciens* E.F. Sm. and Towns) was found on two or three roots at Rothamsted.

Rust (*Uromyces Betae* (Pers.) Tul.) was moderate in October on Little Hoos field.

Leaf Spot (*Ramularia beticola*) was found on one plant and (*Phyllosticta Betae*) occasionally on Little Hoos field.

Leaf Scorch (?physiological) was moderate on all sugar beet at Rothamsted.

Heart-rot, now ascribed to boron deficiency, was found fairly commonly in certain plots of the "nitrogen manure, spacing and date of sowing" experiment on Little Hoos field. It was more common on the early than on the late sown plots.

Kale

Downy Mildew (*Peronospora parasitica* (Pers.) Tul.) was moderate on a commercial crop in Fosters field, Rothamsted, and plentiful on Lansome field, Woburn, in a crop planted in August.

White Blister (*Cystopus candidus* (Pers.) de Bary) was slight at Rothamsted at the end of January.

CARROT

Violet Root Rot (*Helicobasidium purpureum* (Tul.) Pat.) was found at harvest on a few roots on the experiment on Lansome field.

FARM REPORT, 1935

Weather

The year October, 1934, to September, 1935, was remarkable for the wide variations of rainfall from the monthly averages. Very wet spells alternated with very dry spells throughout the year. October and November were dry; December had an average of more than twice the normal rainfall for the month; January and March were dry, the latter providing 1.5 inches of rainfall below normal; in April the fall was just under 4 inches, twice the normal; late May and early June were very wet, and the early part of August very dry; the September rainfall totalled 4.47 inches, nearly twice the normal for the month. The total rainfall for the year amounted to 30 inches, 1.48 inches above the average.

The winter was abnormally mild, and frosts were almost entirely absent before Christmas. Frosts occurred after Christmas, but were neither severe nor prolonged. The mean temperature for the year was 2°F. above the normal of 48.1°F. In ten of the twelve months the mean temperature was above normal, the outstanding month being December, 1934, with an average of 7°F. above normal. The only two months in which the average was below normal were November, in which month the difference was only 0.1°F., and May, in which month the severe late frost occurred. On the night of May 16th, 1935, an unusually late and severe frost was experienced, 9° of frost being recorded.

In spite of the high average temperature, the total sunshine for the year was 19.4 hours below the 42-year average of 1,562.4 hours. Nine months showed a deficit; the greatest increase was provided by July which, with a total of 280 hours, gave almost 78 hours in excess of the normal.

Weather and Crops

The wet December severely interfered with the sugar beet lifting and prevented any ploughing. The dry January provided the opportunity to get most of the ploughing done, and spring corn-sowing was mainly carried out in March. The heavy rain in May and June made the grass grow ahead of the stock, and several fields, besides those originally shut for hay, were mown. The start of haymaking was delayed until June 21st by rain. Conditions during the making, however, were excellent, and in spite of the lateness in cutting, the hay was of good quality. Usually haymaking and root singling both demand labour at the same time, but this year all singling was finished by the time the cutting commenced.

Harvest commenced on July 31st, 1935, with spring oats. Conditions generally were good, though a wet spell at the end of August delayed the finish of harvest. Stubbles broke up well. The wet September prevented dung carting and interrupted the ploughing for winter corn.

The severe frost on May 16th, 1935, damaged the first-formed flowers of the winter beans and the final yield was reduced. The plants were rather more forward than usual at that date owing to the warm winter and spring, and the effect of the frost was therefore more severe. No damage was done to other crops. Cold winds persisted throughout May and retarded all growth.

The tilth of the winter corn crops was quite firm in spring, there being not sufficient frosts to make the ground puffy.

It was found difficult to prepare a suitable seed bed for the spring oats after sugar beet. The ground was severely puddled during the lifting and carting of the beet in December, and there was little time for frost action between ploughing and sowing.

The year was a favourable one for weeds; charlock, mayweeds and poppies were especially prevalent.

Classical Experiments

Broadbalk was ploughed twice, once immediately after harvest and again shortly before drilling. The plots were drilled on October 23rd, under good conditions. The section fallowed in 1934 showed up during the year by its more luxuriant growth, and every plot on this section and the 1933 fallow section was laid at harvest. Of the other two sections only the dunged plot and the plot receiving the heaviest dressing of sulphate of ammonia were laid. Black Medick and a species of Lathyrus were present in rather larger amounts than usual, especially on certain plots. A few wild oats appeared on the dunged plots but these were hand-pulled before harvest.

The half-acre wheat after fallow was badly attacked for the second successive year by wireworm and wheat bulb fly (*Hylemyia coarctata*). The plant was consequently thin and the yield low.

The plant of wheat on Agdell was rather thin throughout the year and the ground became rather weedy. Coltsfoot (*Tussilago Farfara*) was especially troublesome on the half which grew beans in 1934. The wheat ears were severely damaged by house sparrows during July, and the crop had to be cut and carted before it was fully ripe.

Hoosfield barley plots were drilled with Plumage Archer barley in six-inch rows early in March. Good growth was made throughout the year, and all plots stood well at harvest. Plot differences showed up well this year. The crop was cut and carted under ideal conditions. Threshing took place in January, 1936, and the grain from all plots was bulked and sold for malting. The nitrogen content expressed as the percentage of the dry matter was 1.57 and the calculated extract obtainable from the resulting dry malt was 99.8 per cent. After harvest the stubble was surface ploughed and was worked by harrows at intervals until the winter ploughing.

Ploughing of Barnfield commenced on December 1st, 1934, but was not finished until January 18th, 1935. The field was cultivated and ridged in spring and then worked down for the seed bed. Drilling was done at the end of April but germination was slow and the rows appeared gappy. A survey of the field showed that almost every plant was badly attacked by the Pigmy Mangold Beetle (*Atomaria linearis*). A similar attack was recorded in 1934, but did not destroy the plant. The field was worked as soon as weather conditions allowed and was resown with a mixture of swedes and mustard. A dry spell followed the sowing and only a few isolated plants appeared, even the mustard failing to germinate. The field remained uncropped for the rest of the season but sufficient cultivations were given to keep down weeds. Thistles soon appeared, but there was a remarkable absence of annual weeds. The rain later in August enabled the annual weeds to germinate, the dunged plots being most thickly populated.

The Park Grass plots were severely harrowed in spring and were rolled after the application of manures. The hay was made and carted under good conditions but the yield appeared rather smaller than usual. The second cut was made late in September, the grass being cut and carted in the green state.

The exhaustion land on Great Hoosfield was sown with Victor wheat after barley. Initial growth was quite good, but this was not maintained, the plants later becoming small and stunted with red leaf tips. The old manurial strips which last received manure in 1901 were again noticeable, and the area was harvested according to the old plots. The yield from the two plots which had received dung was very much greater than any other plot.

Modern Long-Term Experiments

Four-Course Rotation. A slight change in the cropping was introduced this year. The seeds mixture, which in past years was undersown in the barley, was replaced by ryegrass sown after the harvesting of the barley and ploughing in of the organic manures. The ryegrass came and grew well during the year, and the yield was good. Some trouble was experienced in ploughing the hard-baked ground after harvest ready for the seeds.

Liming was also introduced, 10 cwt. per acre of ground agricultural lime being applied after potatoes for the barley crop. The potato crop was generally poor, and the yields low, although they were better than in the past two years.

The wheat was the most backward of any on the farm, and appeared quite green on August 1st. It ripened quickly, however, but yields were rather low.

Six-course Rotation. The clover break failed for the fourth successive year, in spite of a very heavy seeding. A good plant was established by autumn, but this disappeared in the spring. The fungus *Sclerotinia trifoliorum* was present but the attack did not seem severe enough to account for the almost total failure of the crop. When the seeding of the barley for the 1936 clover crop was made, the adjacent area was sown with seed inoculated with two different bacterial strains to see if any improvement could be secured by this means.

The break which has in the past been sown with a forage crop was sown this year with rye alone. In 1934 the forage crop was harvested as a mature rye crop, owing to the scarcity of tares and beans in this and past years.

Ground agricultural lime is now applied at 10 cwt. per acre to each plot twice in the rotation, before barley and after potatoes. It is hoped this will increase the length of life of the clover plant.

Three-course Rotation (*Straw and Green Manure*). A noticeable feature this year was that the barley plots which were manured in 1934 and had rye ploughed in before the barley were lighter in colour and the plant was smaller. The mean yield of these plots, although good (33 cwt. per acre) was well below that of the other treatments. The depression observed last year from rye ploughed in for beet was not apparent this year. In fact, the beet plots which had rye ploughed in gave the highest yield in 1935.

Three-course Rotation (*Cultivation*). The difficulty found in preparing a suitably clean seed bed for the mangold break after the rotary and tine cultivation mentioned in the 1934 Report appeared again this year. The 1934 wheat stubble quickly became weedy after harvest, and after the spring cultivation these weeds took root again. It was impossible to see the rows until the whole area had been hand-hoed. The two worst weeds were Slender Foxtail (*Alopecurus agrestis*) and Bladder Campion (*Silene inflata*). An autumn cultivation will in future be done on the wheat stubble to prevent this trouble. The mangold seed was treated with magnesium sulphate and phenol as a preventative against PigmyMangold Beetle attack. The average yield of approximately 20 tons per acre was lower than the 1934 average but was due to the smothering action of the weeds in the early stages.

The wheat plant was rather thin and the average yield of approximately 21 cwt. per acre was about 2 cwt. per acre lower than in 1934. The barley yields, however, showed a great improvement over last year's figures, this year's average of approximately 34 cwt. per acre being about 8 cwt. higher than in 1934.

Annual Experiments

The number and area of plots under annual and long-term experiments was increased again this year. The number of plots was 875, occupying 18.44 acres. The usual trouble was experienced in obtaining casual labour for singling roots, and when this was obtained the quality of the work was very poor.

Sugar beet. All beet plots were drilled and singled earlier this year. All sowing was done before the end of April and singling by the middle of June. Kleinwanzleben E. seed was used on all annual experiments though Kühn was retained for the rotations. Slight attacks of the Pigmy Mangold Beetle and Flea Beetle were recorded. The beet in the narrow spaced rows looked small and yellow late in summer, and the individual plants were very small. The first sown beet (mid-March) showed a large number of bolters, the actual percentage being as high as 18. This early sowing also provided the highest tonnage of roots per acre, and the greatest weight of sugar per acre. The sugar content of all beet was lower than in 1934.

Potatoes. The potato crop looked poor and backward throughout the year, and on no plot did the haulms meet in the rows. Plot differences, however, were well marked. Lifting of the crop was delayed by weather, but all tubers came up in a clean and sound condition. The produce of each plot was stored separately in the clamp so that the effect of the manures on keeping quality could be determined. Blight was present in small quantities at lifting time.

Brussels sprouts. The setting of the plants was delayed for many days by the high winds which prevented the application of manures. The plants were set on June 5th and 6th, but were immediately attacked by pigeons. Many plants were pulled right out of the ground and others were stripped of foliage. The area was patched in July and the plants watered in. Further damage was done and replacements were needed up to August. Growth was slow throughout the season and several further gaps appeared. The tops were completely stripped by pigeons in December and the sprouts themselves were next attacked, most of them being made unfit for sale. Only two small pickings were made. The germination of weed seedlings was noticeably smaller on these plots which received soot.

Wheat. The experiment on the time of application of nitrogen to wheat again yielded no significant result. The average yield of all plots not receiving nitrogen was 30.7 cwt. per acre, and the average of those receiving nitrogen was 30.6 cwt. per acre. Early in summer those plots which had received nitrogen could be detected by their darker foliage and more forward growth, but this difference disappeared before harvest.

Beans. Certain plots furthest from the farm buildings were somewhat damaged by birds, but on the rest of the area the plants grew well. Damage was done to the early flowers by the late frost, and this may have affected some plots more than others. The plots not receiving potash either in dung or in mineral form made less rapid growth and formed fewer pods. *Botrytis* disease, though present generally, was more severe on the potash-deficient plots.

Temporary Ley in preparation for Wheat. The seeds on the Pastures field plots looked well during the spring and yielded a good first cut. The vetches and mustard sown after the first cut germinated badly and the only plots on which the rows became visible were those which had received the full year's fallow. Even on these plots the germination of mustard was worse than the tares. The green crops were resown after rain late in August, and fair germination resulted. Once again the germination was best on the plots which had received the full year's fallow.

Insect Pest Control. Two investigations on the control and eradication of insect pests were commenced during the year. The piece of Pastures field where the oat crops failed in 1934 owing to attack by the oat eelworm (*Heterodera schachtii*) was treated with fumigants, and oats were again sown. Drilling was late, owing to delay in obtaining the fumigants. The other pest under investigation was wireworm. The piece of grassland between Pastures field and Knott wood was ploughed in late spring, treated with fumigants and sown with sugar beet. In both experiments the fumigants were applied in the plough furrows during the ploughing.

Both crops grew well at the start, but certain plots (Cymag-treated) became very stunted later. The stunted oat plots became thick with may-weed and gave a negligible yield. The beet on the Cymag-treated plots were small and fanged, the roots spreading almost horizontally a few inches below ground-level. The beet on the other plots were normal and the roots of good shape. When both the oat and beet plots were ploughed up after the removal of the crop there was a distinct smell of the fumigants.

Adco. A new method of preparing the straw for Adco was used this year. The barley straw used was soaked for a day in a water tank. After the surplus water had drained off the straw was heaped in layers, and the Adco powder was sprinkled on each layer. The heap was turned only once during the summer. The quality of the resulting product was much better than that produced by the old method of sprinkling the straw with water.

Cropping, 1934-35

Pastures field was dunged for kale this year. Most of the field was dressed in autumn, 1934 and the rest in spring, 1935. The field was drilled with marrow-stemmed kale early in May. The plants came fairly well and little trouble was experienced from the flea-beetle. The field became rather weedy, especially on the site of the 1934 cultivation experiment. The worst weeds were may-weed and iron grass (*Polygonum aviculare*). The plant, although patchy, was fairly thick and grew ahead of the weeds.

Harwood's Piece, the field taken over in 1934 after the purchase of the estate, bore its first crop for several years. It was fallowed in 1934 but drilled with Thousand Head Kale early in May, 1935. Growth was slow throughout the year and charlock and docks were plentiful. Much hand and horse labour had to be expended to keep the field reasonably clean. A small area was dusted with copper sulphate at 20 lb. per acre with quite good results. Most of the kale was folded by sheep during the winter, though about $1\frac{1}{4}$ acres of it were sold for human consumption.

In 1934 the winter beans drilled in Great Harpenden Field were severely damaged by birds, and a very thin and uneven plant resulted. To minimise this damage the beans in Great Knott in 1935 were ploughed in, the beans being placed in the bottom of every second furrow by an attachment fitted to the plough. A rather heavier seeding than normal was given to allow for possible damage. No damage occurred and the crop came up thick and clean. Two harrowings were the only cultivations given and these were sufficient to keep down weeds until the plants met across the rows. The resulting crop gave a large bulk of straw which was poorly podded, partly due to frost killing the flowers and partly to the thickness of plant in the rows. While in the shooks the beans were worried by pigeons. The stubble, which was the cleanest that had been obtained for several years, was grazed by pigs until ploughing.

Fosters was drilled with Plumage Archer barley on two dates, after folded and cut kale. The plant grew well, but the dung applied for the kale, and the folding of sheep, caused much of the crop to be lodged. The yield was good but much grain was lost during harvesting.

Great Harpenden field was drilled with Victor wheat after beans. A top dressing of 1 cwt. of sulphate of ammonia was given in March and a small part of the crop was laid by a thunderstorm shortly before harvest. The crop yielded approximately 28 cwt. per acre. The wheat precision plots and the experiment on the time of application of nitrogen were also situated here. The area immediately surrounding these plots was drilled with Little Joss spring sown wheat. This was badly disturbed by birds and only a thin plant resulted. Linseed was then drilled among the wheat but the mixed crop was again badly damaged by birds just before harvest.

The spring sown Marvellous oats in Long Hoos came well despite the rather rough tilth. A top dressing of sulphate of ammonia was given in March and a good thick plant resulted which stood and yielded well. The crop was harvested under ideal conditions.

The plots of the spring oat variety trial yielded well, the only plot yielding much below the others was the non-Ceresan treated "Marvellous" plot. On this plot the plant appeared later and remained thinner and more weedy throughout the Summer. The following table gives the yields of the different varieties :

Variety.	Yield, cwt. per acre. Grain.	Straw.
Star	33.3	38.8
Marvellous	31.5	39.0
Progress	30.4	39.6
Marvellous (own seed)	30.0	36.0
Eagle	29.0	40.6
Golden Rain	27.7	40.3
Marvellous (untreated)	23.2	31.3

The northernmost six acres were undersown with seeds but these failed, and after harvest three acres were cultivated up and drilled with rye for spring sheep feed.

Little Hoos was devoted to the annual experiments described elsewhere.

Pennell's Piece was sown with Danish Steel Monarch wheat. The crop was considerably damaged by sparrows just before harvest, and the yield was low.

Grassland

The grass was rather late in commencing growth, but was very productive during the summer. Haymaking, although late, was done under good conditions and yields were good. Those fields not cut for hay were topped during the summer. By mid-August the fields were bare but the grass grew again rapidly in September.

A cultivation and manurial experiment on the improvement of the poor grassland in High Field was laid down during spring. The plots which received the severe harrowing produced far less flowering shoots than did the other plots. The remainder of High Field was severely harrowed in April and sows were out-wintered there.

All other grassland was harrowed and rolled in spring.

Livestock

Pigs. During the third contract period (Jan. 1st-Dec. 31st, 1935), 385 Class I bacon pigs were contracted to be delivered to the factory, and 401 pigs were actually delivered from the two farms. The following table gives the percentage grading returns for the two farms separately :

GRADING RETURNS

(*3rd Contract*)

	Total delivered	Grade A.	Grade B.	Grade C.	Grade D.	Grade E.	Under weight.	Over weight.
Rothamsted *	245	18	25	33	22	less than 1	less than 1	less than 1
Woburn ..	156	24	24	26	22	less than 1	3	less than 1

A third pig experiment in the individual feeding pens was started during the summer. The main comparison was between coarsely and finely ground barley meal ; the effect of exercise on the grading of the bacon was also investigated, full measurements of the carcasses being taken at the factory. The pigs appeared much more healthy than in either of the two previous experiments.

Cattle

Six Shorthorn heifers calved down outside in the spring and remained outside with the calves throughout the summer. Other black polled calves were bought in so that each heifer reared two calves for the first period after calving. After weaning in summer a further calf was fostered on and when this was weaned in autumn the cows were dried off and out-wintered cheaply. The cows were bulled to calve in spring, 1936.

Beef prices remained low throughout the year and even with the subsidy the cattle were not making any more than last year.

Sheep. The 1935 lamb crop averaged about 170 per cent., sixteen sets of triplets being born. The lambs were small at the commencement of lambing but those born later were stronger. Ewe losses were rather heavier than usual.

Prices during the year were rather lower than in the previous year. Those lambs not sold fat off the grass were folded on kale during the winter and sold as they became ready.

Electrical Investigations

A brief account of this work is given on page 69.

Buildings

No major alterations or additions have been made to the buildings, but plans for a new pair of cottages and a new Danish type piggery have been prepared and these buildings will be erected during the coming year.

*The Rothamsted figures include many pigs from the third pig experiment.

Following upon the success of the new method of preparing straw for Adco, plans have been drawn up for a new set of buildings for the making and storing of Adco. The plans also incorporate two cattle feeding boxes so that farmyard manure of known quality can be prepared for experimental purposes.

Show Successes

At the Smithfield Club's Fat Stock Show in 1935, we secured the 6th prize for a bacon pig carcase (160-220 lb. live weight), and were commended for three crossbred fat lambs.

At the Redbourne District Annual Ploughing Match the following awards were gained :

1*st Prize.*	Best turnout (F. Stokes).
1*st* ,,	Corn drilling (F. Stokes).
2*nd* ,,	Best turnout (C. Mepham).
3*rd* ,,	Horse ploughing (F. Stokes and H. Currant).

The Certificate of the National Horse Breeders' Association and the R.S.P.C.A. Merit Badge were also awarded to F. Stokes.

Implements

We now have at our two farms a large collection of modern farm implements which have either been presented or loaned to us by many of the leading implement manufacturers. They form a source of great interest to the many parties of practical farmers who visit us, and detailed information concerning the quality of their work and their suitability to our land is given when required. The firms who have helped us to make this collection and to whom we are indebted are as follows :

Allen & Simmonds, Ltd.	Motor hoe.
J. Allen & Sons.	Motor scythe.
Bamfords, Ltd.	Hay machinery.
E. H. Bentall & Co., Ltd.	Cake breaker.
Blackstone & Co., Ltd.	Swathe turner.
Cooch & Sons.	Potato sorter.
Cooper, McDougall & Robertson, Ltd.	Sheep dipper.
Cooper, Pegler & Co., Ltd.	Spraying machinery.
The Cooper-Stewart Engineering Co., Ltd.	Sheep shearing machine.
The Dawewave Wheel Co.	Tractor wheels.
Dunlop Rubber Co., Ltd.	Rubber wheels, paving bricks.
Ford Motor Co., Ltd.	Tractor.
R. G. Garvie & Sons.	Grass seed broadcaster.
General Electric Co.	Electric motors.
Harrison, McGregor & Co., Ltd.	Root pulper, manure distributor.
J. & F. Howard, Ltd.	Ploughs, potato digger.
International Harvester Co., Ltd.	Tractor, drill, manure distributor.
A. Jack & Sons, Ltd.	Root drill and hoe.
L. R. Knapp & Co., Ltd.	Manure and root drill.
R. A. Lister & Co., Ltd.	Oil engine, sheep shearing machine.

https://doi.org/10.23637/ERADOC-1-67

Miller Wheels, Ltd.	Tractor wheels.
G. Monro, Ltd.	Motor hoe.
Parmiter & Sons, Ltd.	Rake and harrows.
Ransomes, Sims & Jefferies, Ltd.	Ploughs, cultivators, drills, grass rejuvenator.
Ruston, Hornsby, Ltd.	Grain drill, binder.
Tarpen Syndicate Co., Ltd.	Portable petrol generating equipment.
Transplanters, Ltd.	Robot planter.
J. Wallace & Sons, Ltd.	Manure sower, potato planter.
J. Wilder.	Pitch-pole harrows.
W. A. Wood & Co., Ltd.	Mower, spring tine harrows.

Staff

H. M. Edginton spent about six months here as a voluntary worker to help with the livestock experimental work and field observations. F. R. Russell also spent a short time during the winter helping with general recording and field observations.

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 following observations under this scheme are taken daily, at 9 a.m. G.M.T.:

Temperatures—maximum and minimum in screen, minimum on grass, 4 inches and 8 inches under bare soil, dry and wet bulb in screen; *Rainfall*—8-inch gauge; *Sunshine*—duration by Campbell-Stokes recorder; *Weather*—Beaufort letters; *Wind*—direction and force; *Visibility*; *State of Ground.*

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.

The above observations are supplemented by the following records, for the use of the Meteorological Office:

Barometer and attached Thermometer; Solar maximum; Temperature—1 foot under bare soil; *Cloud*—amount, form and direction; *Sunshine*—hourly values of duration. With the exception of the last, all these observations are also taken at 9 a.m. G.M.T.

The following additional observations are also made, to maintain the continuity of the Rothamsted meteorological records:

Temperature under grass at 4 inches, 8 inches, and 1 foot, taken at 9 a.m. G.M.T.; *Wind*—direction and force at 3 p.m. and 9 p.m., G.M.T., taken from chart of recording anemo-biagraph; *Rainfall*—5-inch gauge taken at 9 am. G.M.T.

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. Recently, a Gorczynski Radiometer for measuring the radiant energy of the sun has been installed, under the Agricultural Meteorological Scheme.

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

Three drain gauges, each of one-thousandth of an acre in area, originally installed by Lawes in 1870, and fitted with continuous recorders in 1926, give the drainage through 20 inches, 40 inches, and 60 inches of uncropped and undisturbed soil. A continuously recording 6-inch rain gauge is used in conjunction with these.

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

Atmospheric Pollution.—A gauge for measuring the amount of solid matter deposited from the atmosphere has been in use for some years in connection with the scheme of observations arranged by the Atmospheric Pollution Research Committee of the Department of Scientific and Industrial Research. In February, 1933, a gauge for measuring atmospheric sulphur dioxide was also set up. The results are discussed on page 68.