ROTHAMSTED RESEARCH

Report for 1934

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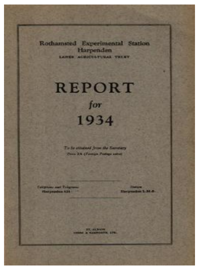

Rothamsted Report for 1934

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Rothamsted Research (1935) *Rothamsted Report for 1934 ;* Report For 1934, pp 19 - 88 **- DOI: https://doi.org/10.23637/ERADOC-1-66**

REPORT FOR 1934

THE PURCHASE OF THE FARM: FURTHER DEVELOPMENTS

The outstanding event of 1934 was the purchase of the farm and a further part of the estate by the Rothamsted Trustees. Up till the spring of this year the estate has been in the hands of the Wittewronge family and their descendants, the Lawes, since 1623. When Lawes laid down his experiments in the period 1843 to 1856 he put them into whichever field best suited the purpose: in consequence the experimental area was not in one piece but in three, widely separated; further, the laboratory was built away from all these. So long as the estate remained in the family as an agricultural enterprise this did not matter: whatever additional land was needed could easily be taken over, and in practice it was retained as long as necessary. But with the letting of the house and the dispersal of the family it was no longer possible to work in this way, and the builders were eating into the neighbouring fields at an alarming rate so that our farm was rapidly acquiring building value. Rothamsted is well known all over the world and very few people realised that the Station did not own the land it cultivated, nor even the land on which the laboratories were built. All was in the hands of the Lawes-Wittewronge family: some was held on a monthly tenancy, some was subject to six months, and some to one year's notice; the classical fields and certain others were on a long lease; but this would inevitably terminate.

It was recognised by all concerned that the importance of the Rothamsted work demanded the safeguarding of the Rothamsted fields for all time, which could be secured only if the Rothamsted Trustees became the owners. Negotiations for purchase were begun in May, 1931; they were necessarily very protracted, but the contract for purchase was signed on March 16th, 1934, and the purchase was completed eight weeks thereafter, on May 18th. The estate thus transferred to us consists of the Manor House, the farm manager's house, eight cottages (three of them large enough to be let on yearly tenancies), Knott Wood, the site of the laboratories, the experimental and ordinary farm fields and sufficient land in addition to preserve the amenities of the house and so keep it as an asset of value rather than a burden, and, even more important, sufficient land to enable us to carry out field and farm experiments on a scale corresponding to the importance of the work. The total area of land acquired is 527 acres. The basal price agreed was £30,000 without timber and subject to adjustments in regard to tithe; also there were certain obligations as to fencing: the total cost including legal and surveyor's expenses, timber, tithe adjustment and all incidental charges including also certain reparations, amounted to £35,000.

Three possible means of raising the necessary purchase money had been considered: a loan; sale of Trust securities; and public subscription. The two former were dismissed as being completely

https://doi.org/10.23637/ERADOC-1-66

crippling to the work of the Institution: there would be no point in owning the land if nothing could be done with it. It was therefore decided to appeal to the public for the full amount so as to enable the Station to start on its new career free of debt.

On March 19th the letter of appeal, signed by the Duke of Devonshire, President of the Society for Extending the Rothamsted Experiments; the Earl of Stradbroke, President of the Royal Agricultural Society; Sir Gowland Hopkins, President of the Royal Society; Mr. Stanley O. Ratcliff, President of the National Farmers' Union; Sir Daniel Hall; and Lord Clinton, Chairman of the Lawes Agricultural Trust Commitee, was published in *The Times* newspaper, and shortly after in all the leading papers of the country. Rothamsted owes a great debt of gratitude to the Press for the amount of publicity given to the appeal. Sir Bernard Greenwell started the fund with £1,000; when it appeared to be hanging fire Mr. Robert McDougall, who had seen the appeal and the editor's commendation in the *Manchester Guardian*, offered £15,000, and the Sir Halley Stewart Trust £5,000, on condition that the full amount was collected in time. These noble gifts stimulated all the friends of Rothamsted to their fullest activity, and it was not uncommon to receive £500 or more in a single day. Handsome contributions of £500 each were received from the Royal Agricultural Society, the National Farmers' Union, and Imperial Chemical Industries. T. H. Riches, Esq., gave £350, the Chartered Surveyors' Institution gave 250 guineas, the Beet Sugar Factories Anglo-Dutch Group, Messrs. J. Bibby & Sons, Ltd., British Oil & Cake Mills, Ltd., Bury Group of Sugar Beet Factories, Sir Wm. Waters Butler, Rt. Hon. Lord Clinton, Dunlop Rubber Company, Ltd., J. G. McDougall, Esq., I. D. Margary, Esq., Messrs. R. Silcock & Sons, Ltd., Owen H. Smith, Esq., each gave £250; the Institute of Brewing, Simon Marks, Esq., I. M. Sieff, Esq., £200 each; and the Highland and Agricultural Society of Scotland £150. Many other societies and individuals contributed £100 or more, and the Brewers' Society encouraged its members to give handsomely. Some of the small donations were accompanied by most charming letters. Collections were made by village school teachers, by farmers and others on market days and at branch meetings, while many working farmers sent direct to us. Finally the Carnegie Trustees made success certain with a noble grant of £2,000. The whole sum of £35,000 was raised several days before the appointed time and the total cost of the appeal was only £40.

On June 20th, 1934, the Minister of Agriculture, Mr. Walter Elliot, accompanied by Sir C. J. Howell Thomas, Permanent Secretary of the Ministry of Agriculture, attended the Annual Summer Gathering at Rothamsted and formally handed over the deeds to Lord Clinton, who accepted them on behalf of the Trustees.

The various obligations and reparations were at once undertaken and the station is now in full possession of an ample area of land with its boundaries so arranged that it will suffer little or no damage from the activities of the local builders. Messrs. Alfred Savill & Sons acted as surveyors, and Messrs. Raymond Nix & Barker as solicitors on our behalf.

Some further developments are being at once put in hand. The glass houses are to be extended so as to give ample accommodation to the Mycologist, Mr. Geoffrey Samuel, who is studying plant diseases caused by soil fungi. Advantage is being taken of our new position as owners to plan out the land behind the laboratories for future development so as to avoid the congestion and inefficiency that always follows when development proceeds haphazard. A new wing is to be added so as to relieve the congestion in the older departments by setting up new biochemical and bacteriological laboratories. The James Mason bacteriological laboratory erected in 1906 has proved a remarkably fertile source of agricultural and scientific discovery, and its success has necessitated considerable enlargement. It is further proposed to extend the farm buildings and replace the present wooden piggeries and stores—erected in 1921 and 1922 from old Army huts—by modern brick buildings better suited for their purpose. Finally, it is intended to lay out the fore-court in front of the laboratories in accordance with the very dignified design of Mr. Walter Tapper, R.A. A sundial is being made by Sir Charles Vernon Boys. It is expected that these various developments will cost some £25,000 towards which we hope for substantial Government grants: a considerable sum, however, will still have to be raised from private donors and others.

THE PRODUCTION OF CROPS

The practical purpose of the experiments on crop production is to discover how crops may be raised in larger quantity per acre, at lower cost, and of better quality. In view of the great variety of conditions of soil and climate in Great Britain it would be of little use for us merely to achieve these ends on our own farm: the work has to be put on a much wider basis and it resolves itself into a series of investigations to discover the influence of soil, climate, manuring and cultivation on the yield, composition and quality of crops. Thanks to the generous collaboration of farmers in all parts of the country, and to the enlightened co-operation of some of the larger commercial and agricultural organisations, it has been possible to repeat typical experiments at a large number of outside centres: Mr. Garner has been, as before, in charge of this work. The new methods of field experiment designed at Rothamsted have proved exceedingly valuable and have given to the results a degree of trustworthiness that would otherwise have been quite unattainable. The investigation of the composition of the crops grown under these various conditions has thrown a vast amount of work on Dr. Crowther and the staff of the Chemical Department and explains the need for laboratory extensions. The study of crop quality, however, necessitates special procedure, as "quality" is an exceedingly elusive property which can in no case be defined with accuracy. The method adopted at Rothamsted is to produce a series of samples of known agricultural history, then submit them to expert buyers or users of the crop who grade them in classes. Efforts are then made to relate the grading to the chemical composition.

"Quality" is thus defined as "commercial desirability": it has no necessary connection with nutritive value. So far we have failed to find any method whereby the nutritive value of the different grades of produce can be discovered, short of very elaborate and exceedingly difficult feeding tests on human beings which would be more appropriately carried out under medical supervision than by us. For the farmer commercial desirability is the important test: it is useless for him to produce something the market does not want. In point of fact the ordinary diet of the Englishman is so varied that variations in chemical composition of the raw materials supplied by the farmer are probably not very important; attractiveness and palatability are, however, important, and on these points the expert buyer can advise.

The crops studied in detail have been barley, wheat, sugar beet and potatoes. A beginning has been made with grass and fodder crops: naturally by different methods because the feeding test can be applied to these.

Broadly speaking the results have been that "quality" is determined primarily by the general soil conditions and is not much affected by manuring, while quantity is largely determined by the manuring. Usually the highest crop obtainable by normal manuring is of as good quality as can be obtained on the farm: the scheme of manuring can therefore be drawn up chiefly with the view of securing quantity. The management of the crop, however, affects its quality, and serious losses may easily occur through avoidable causes.

Wheat. Work on the quality of wheat is done in association with the Research Institute of British Flour Millers, St. Albans. Certain physical properties of dough are so closely allied to the properties of clay that they are studied in the Physical Department, but the workers are in constant communication with those at St. Albans. The effect of manuring on the composition of the gran is not very marked. It would be impossible to find two more widely different treatments than on the Broadbalk unmanured and tihe Broadbalk fully manured plots, yet the Vitamin B content of the wheat grain was found to be the same for both by Dr. Leslie Harris of the Dunn Nutritional Laboratory, Cambridge.

Barley. In March, 1934, the investigations on malting barley which had been carried on since 1921 under the Research Scheme of the Institute of Brewing, were transferred to the School of Biochemistry and Brewing of the University of Birmingham, where malting and brewing investigations are more appropriately made; this was done in March, 1934. The Director still remains Chairman of the Institute's Barley Committee so as to ensure continued close contact with the work. In October, 1934, a Conference was held at Rothamsted between the barley growers and the buyers, at which some 200 samples of malting barley were exhibited and discussed. 1934 was a bad season for malting barley, in contradistinction to 1933, when good samples were common.

The samples had been graded by experts, who then explained to the growers the reasons for the grading and the faults which had detracted from the value of otherwise satisfactory samples. Premature harvesting, faulty stacking, and wrong setting of the threshing machine had been responsible for a certain amount of low grading. The Conference served a very useful purpose and will be repeated in October, 1935.

Sugar Beet. A scheme was inaugurated in 1933 whereby Rothamsted carries out fertiliser experiments on commercial sugar beet farms in association with the Committee on Sugar Beet Research and

Education set up by the beet sugar factories and the Ministry of Agriculture. These experiments were continued in 1934 and it is hoped to put the work on to a permanent basis ; if sugar beet is to be continued as an English crop the yields must be increased, and all experience shows that the surest way of doing this is by suitable cultivation and manuring. Hitherto the advice given to farmers has been based on Continental recommendations. It by no means follows, however, that a scheme which answers well in Czechoslovakia or in Holland will also answer in England and in point of fact our experiments do not in general support the recommendations made to farmers. Hitherto the experiments have not been sufficiently numerous to justify us either in condemning the old or in putting out new recommendations, but if the co-operation with the Factory Committee can be continued we hope to remedy this defect.

The average yield of sugar beet in England is only about 9 tons per acre, as shown by the following figures :

1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
8.1	7.7	8.6	6.5	7.7	8.7	8.8	7.1	8.7	9.0	10.1 (1)

This is considerably lower than on the Continent. Average yields for the last nine years (1925-1933) are in tons per acre :

Holland	13.4	France	10.8	Hungary	8.2
Denmark	11.9	Italy	10.6	Great Britain	8.2
Sweden	11.9	Czechoslovakia	10.0	Finland	7.5
Belgium	11.9	Austria	9.7	Roumania	6.9
Germany	11.5	Spain	8.8	Jugo-Slavia	6.3
Ireland	11.2	Poland	8.5	Bulgaria	6.3
				Turkey	4.3

(1) Provisional

The average yield on our experimental plots has been :

	Washed Roots, tons per acre. 1933	Washed Roots, tons per acre. 1934	Sugar, cwt. per acre. 1933	Sugar, cwt. per acre. 1934
Rothamsted (2)	6.5	14.0	21.0	47.6
Woburn (2)	9.2	18.4	32.4	63.8
Mean of outside Centres	11.5	13.5	37.5	47.6
Average for England	9.0	10.1	29.5	34.7

(2) Spacing Experiments

Our yields are therefore considerably above the average. None of these yields, however, except perhaps that at Woburn, is really satisfactory, and we ought to aim at crops of 18 to 20 tons per acre as the usual thing, and not as the exception.

How to secure it is not at all clear. In the 1934 experiments 27 different combinations of artificial fertilisers in dressings ranging up to 12½ cwt. per acre of the complete mixture were tested at 15 different centres, but the results were only small ; the effect of manures was on the average :

Mean yield per acre. Washed Roots. tons.	Mean yield per acre. Sugar. cwt.	Increase in sugar in cwt. per acre for 4 cwt. sulphate of ammonia.	6 cwt. superphosphate	2½ cwt. Muriate of Potash.
13.47	47.6	+3.0	+0.9	+0.4

	Sulphate of Ammonia.			Superphosphate.			Muriate of Potash.		
Cwt. per acre	0	2	4	0	3	6	0	1¼	2½
Roots, tons per acre	12.9	13.5	14.0	13.3	13.4	13.6	13.4	13.6	13.4
Tops, tons per acre	9.6	10.7	12.3	10.7	10.9	11.0	10.9	10.9	10.8
Sugar, per cent.	17.9	17.7	17.5	18.0	17.7	17.4	17.6	17.8	17.8
Sugar, cwt. per acre	46.0	47.8	49.0	48.1	47.5	47.2	45.0	48.4	49.4
Purity per cent.	88.9	88.3	88.0	88.4	88. 4	88.4	88.4	88.5	88.4

Of these increases only that given by the sulphate of ammonia is of much significance. Nitrogenous manure almost always increased the tops, but it did not increase the roots to the same extent : it depressed the sugar content and the purity of the juice, but to a less degree. The gain in roots more than compensated the loss in sugar percentage, so that a net gain of 3 cwt. per acre of sugar was obtained on the average by the use of 4 cwt. sulphate of ammonia. The response differed at the different centres : at only half of them was it significant ; it amounted on the average to a gain of only 6 per cent ; the gain is, however, profitable, and the effect is greater than in 1933. The mineral fertilisers were almost ineffective : 6 cwt. per acre of superphosphate added on the average less than 1 cwt. sugar per acre : it gave significant increases at one or two centres only, the increase amounting to rather less than 3 cwt. sugar per acre. Potash was of no direct benefit ; indeed, at one centre it appeared to depress the yield of roots ; it tended slightly to raise the sugar content, especially when in combination with nitrogen.

It is difficult to understand why the potash and phosphate should have so little effect, and experiments are made both at Woburn and at Rothamsted to seek an explanation. It seems improbable that these yields are the highest possible, and the experiments should certainly be continued to find some way of inducing the crop to make bigger growth.

It may be that the ordinary way of adding these fertilisers is not very effective, and several experiments have been made to test other ways of incorporating them with the soil : the results, however, have been quite small ; the yields of washed roots were, in tons per acre :

	1931 Woburn	1933 Woburn	1933 Rothamsted	1933 Rothamsted	1934 Woburn	1934 Rothamsted
Usual harrowing ..	11.64	9.44	5.21	6.08	18.24	14.81
Special incorporation..	10.56(1)	9.01(2)	6.51(3)	6.96(2)	18.52(2)	15.58(3)
No minerals	—	—	4.79	—	18.59	—

(1)' Simar " rotary cultivator ; (2)ploughed in ; (3)in subsoil.

The incorporation of the minerals has thus been without effect at Woburn though it appears to have been beneficial at Rothamsted. Nevertheless the subsoil plays a very important part. Experiments at Woburn showed that the sugar beet roots penetrate deeply into the soil. Apparatus was designed to trace the movement of the roots : before the season was over they were at least five feet down. At centres where, during the drought, there was much free subsoil water, the yields of tops were higher than the average, the purity of the juice was lower, and there were indications of a better response to phosphate.

It may be that application of the manures right alongside the seed would be more effective.

Experiments have been started at Rothamsted to test the effect of various cultivations, *e.g.*, rolling the seed bed on plots receiving farmyard manure and on those receiving artificials only. Heavy rolling was harmful and reduced the yield by 9 cwt. washed roots per acre, but sulphate of ammonia counteracted the bad effect to some extent.

Farmyard manure acted as if its nitrogen had less than half the

https://doi.org/10.23637/ERADOC-1-66

effectiveness of that in sulphate of ammonia but as it did not depress the sugar percentage its production of sugar was better than that suggested by the yield of roots. Thus in a comparison between 10 tons of dung and 3 cwt. sulphate of ammonia the results were :

	Dung.	Sulphate of Ammonia.
Approximate quantity of nitrogen in manure, lb. per acre	150	70
Mean increase in yield of washed roots, tons ..	1.26	1.61
Mean increase in yield of tops, tons	2.08	4.60
Mean effect on percentage of sugar	−0.06%	−0.38%
Mean increase in sugar per acre, cwt.	4.1	4.4
Mean effect on plant numbers, thousands ..	+2.4	−1.6

The yield and sugar content of the roots depends upon the spacing but the effect varies with the season. In 1933 with a rather small crop, 10-inch spacing gave much higher yields and somewhat higher sugar content than 20-inch spacing : in 1934 there was very little difference, but at Rothamsted 20-inch spacing was somewhat the better and at Woburn 15-inch spacing : the 1934 results were :

Mean Effect of Spacing: **1934.**

	Plant Number, Thousands per acre.		Washed Roots, Tons per acre.		Sugar, Cwt. per acre.	
	Rothamsted	Woburn	Rothamsted	Woburn	Rothamsted	Woburn
20 in. rows	32.2	33.4	14.54	18.31	49.2	63.9
15 in. rows	42.5	42.9	13.68	19.17	47.0	66.0
10 in. rows	69.0	63.1	13.87	17.88	47.1	61.4

It is difficult to understand why the results in the two years should have been so different : the two seasons had a good deal in common.

Variations in soil conditions have a very great effect, however, on the yield of sugar beet : the results on different fields at Rothamsted and at Woburn have been in tons per acre :

	Rothamsted Long Hoos 6-course.	Rothamsted Pastures field.	Woburn 6-course.	Woburn Butt Furlong.
1933 ..	2.13	6.52	9.15	—
		Long Hoos		
1934 ..	11.08	15.36	9.73	18.45

Potatoes. The manurial experiments on potatoes were continued at Rothamsted, Woburn, and at outside centres chiefly in the Fen district : some striking results were obtained. In one series of experiments three levels of manuring with artificial manures were tested in 27 different combinations : no dung was used as this is not generally available on the fen soils. The results were :

	Standard Error.	Sulphate of Ammonia cwt. per acre.			Superphosphate cwt. per acre.			Sulphate of Potash cwt. per acre.		
		None	2	4	None	4½	9	None	1½	3
Light peaty fen.										
Wissington ..	±0.386	8.25	9.07	9.18	6.99	9.67	9.83	6.04	9.58	10.88
Thorney ..	±0.560	6.79	7.62	9.10	7.59	7.66	8.26	6.79	8.13	8.59
Clay fen.										
March ..	±0.403	7.56	9.09	10.49	7.00	9.49	10.65	8.80	8.76	9.59
Little Downham	±0.205	12.89	14.94	16.04	11.73	15.50	16.64	14.18	14.85	14.84
Silt.										
Wisbech (early potatoes). ..	±0.138	5.98	7.11	7.15	6.49	6.76	6.98	6.68	6.74	6.83

The effect of superphosphate is as marked as that of nitrogen and the response continues even to the larger dressing. On the light peaty fen, potash also produces a marked increase but on the clay fen its effect is less. The early potatoes on the silt soil at Wisbech were less responsive but still gave definite responses to superphosphate and sulphate of ammonia.

At one fen centre, Wimblington, March, on a light fen soil, the effect of adding dung was tested. Sulphate of potash gave marked responses even in the presence of dung; sulphate of ammonia was less effective. The dressing of 2¼ cwt. each of sulphate of ammonia and sulphate of potash with superphosphate proved nearly as effective as 8 tons of dung per acre. The increases were :

	Mean Effect.	Dung Absent.	Dung Present.
Sulphate of ammonia, 2¼ cwt.	0.56 tons	0.29	0.83
Sulphate of potash, 2¼ cwt.	3.80 ,,	4.93	2.68
Dung 8 tons	5.00 ,,	—	—
Standard errors	±0.177	±0.250	

The investigations on the quality of potatoes begun in 1929 in association with Messrs. Lyons have now been transferred almost entirely to their laboratories, but a few key determinations continue to be made here so as to facilitate linking up with their work.

MINOR ELEMENTS IN PLANT NUTRITION

The investigations on boron are still being continued by Dr. Brenchley and Miss Warington.

Manganese is needed by plants, though only in small amounts ; in its absence they become liable to certain diseases such as grey speck disease of oats. Chemical examination shows that the determining soil factor is not the actual amount of manganese present, but the proportion that exists in the exchangeable form and the tenacity with which it is held.

Molybdenum salts have been found to cause symptoms that look very much like those of Virus disease. This observation is being followed up in the Plant Pathological and Botanical Departments. Mr. W. A. Roach at East Malling has shown that some fruit tree stocks can take up molybdenum from the soil and others cannot.

ORGANIC MANURES

(1) *The Use of Straw as Manure.*

With the increasing tendency to break away from fixed rotations the systematic return of the straw to the land in the form of farmyard manure is becoming more and more difficult and two alternative methods are being compared with farmyard manure at Rothamsted : in one the straw is rotted artificially before being applied ; in the other it is ploughed direct into the land but artificials are added to furnish the necessary food for the micro-organisms effecting the decomposition. The effect is then observed in the year of application and in each of the four succeeding years. For each manure there are thus five plots under each crop in each year, one of which has received the manure during the year, another received it one year ago, while others had it two, three, and four years ago. The straw ploughed in with the appropriate artificials proved at least as useful as farmyard manure, excepting only for the hay crop, which in any case was abnormally low, as also was the yield of potatoes. The details are given later on; averages of the various sets of plots are:

Average yield per acre of five treatments, 1934.

	Wheat grain.	Barley grain.	Potatoes.	Hay, Dry Matter.
	cwt.	cwt.	tons.	cwt.
Dung 1st year and 4 residuals	25.5	24.3	3.61	11.6
Straw (rotted) and 4 residuals..	25.0	23.5	2.98	10.5
Straw (unrotted) and 4 residuals	25.6	26.3	3.82	8.3
Super (annual N and P) ..	25.4	26.1	4.61	15.2
Rock phosphate (annual N and P)	24.7	22.5	3.54	14.1
Mean of all straw manures ..	25.4	24.7	3.47	10.1
Mean of all inorganic manures	25.0	24.3	4.08	14.6

It will be interesting to see whether similar results are obtained in future years: the question is of particular importance on mechanised farms. The equivalent mixture of artificials has been as good for wheat and barley as has the straw, and better for potatoes and hay: superphosphate also proved superior to mineral phosphate.

The residual effects are shown in the following figures, where the yields are expressed as a percentage of the average of the dung and the two straw treatments:

Average yields, 1932-34.

Treatment.	Crop.	Year of Application	Residual Years. First.	Second.	Third.	Fourth.
Farmyard Manure	Wheat	116(3)	96(3)	91(3)	95(2)	94(1)
	Barley	133(3)	98(3)	94(3)	76(2)	88(1)
	Potatoes	140(3)	102(3)	91(3)	96(2)	75(1)
Mean		130	99	92	89	86
Straw rotted artificially	Wheat	123(3)	99(3)	85(3)	97(2)	97(1)
	Barley	109(3)	97(3)	89(3)	93(2)	105(1)
	Potatoes	90(3)	79(3)	80(3)	104(2)	65(1)
Mean		107	92	85	98	90
Straw+artificials ploughed in	Wheat	112(3)	94(3)	102(3)	87(2)	100(1)
	Barley	121(3)	86(3)	96(3)	95(2)	106(1)
	Potatoes	123(3)	89(3)	114(3)	106(2)	122(1)
Mean		119	90	104	96	109

100=mean of the two straw and the farmyard manure results. Bracketed figures show the number of yields on which the figures are based.

The artificial rotting of the straw was not entirely satisfactory and we shall certainly improve it in future years.

(2) *Green Manure.*

As is well known the Woburn experiments on green manuring failed to show any benefit from either mustard or tares grown during the summer and ploughed in as preparation for winter wheat. This was quite unexpected, as the light soil at Woburn is the type of land that seems to need organic matter. The plant residues, however, have to undergo decomposition in the soil before they are of any manurial value to the crop and this decomposition is brought about by micro-organisms which themselves consume plant food. The process is complex and it is not difficult to imagine a train of processes in which the crop would gain nothing, and might easily lose, by the ploughing-in of green manure. Inspection of the plots indicates that the wheat suffers from nitrogen starvation in spite of the added plant residues. Drs. Crowther and Mann have shown that in conditions such as those of the Woburn green manure experiments, considerable loss or inactivation of nitrogen takes place in the soil during the period between the ploughing-in and the active assimilation of soil nitrates by the wheat plant.

The experiment has been repeated in such a way as to reduce this rather long period of waiting. Blue lupins were sown on May 16th : they grew vigorously and produced approximately 50 cwt. dry matter per acre of leaves, stems and roots : they were ploughed-in for kale sown on July 30th. The effect was very striking, the yield of kale being practically doubled. Only the leaves and stems of the lupins were effective, however : when these were removed and only the roots ploughed-in there was no benefit. The yield of kale was, in tons per acre :

Ploughed-in :—	Nitrogen contained in part ploughed-in, lb. per acre.	Kale, tons per acre.
1. Nothing (Lupin tops and roots removed) ..	0	3.53
2. Lupin roots only	11.3	3.17
3. Lupin whole plant roots and tops	133.6	6.68
4. Lupin whole plant plus tops from treatment 2	256	8.47

The Rothamsted soil is much heavier than that of Woburn and would be expected to behave rather differently to green manuring. Autumn sown vetches proved ineffective for the following spring sown crops while autumn sown rye was actually harmful to the barley and the sugar-beet : the results were :

Means of all manurial treatments, yields per acre, 1934.

	Potatoes.	Barley.		Sugar Beet.	
		Grain.	Straw.	Roots.	Tops.
	tons	cwt.	cwt.	tons.	tons.
No green manure ..	5.91	27.2	30.0	12.62	10.63
Vetches ploughed in	5.54	27.2	30.1	11.86	9.10
Rye ploughed in ..	6.14	20.4	25.0	11.59	5.96

Yield of green manures April 13th : rye, 5 tons green weight, 13 cwt. dry matter ; vetches, 0.6 tons green weight, 1.2 cwt. dry matter.

There is evidently a considerable amount to learn about green manuring, and it cannot be recommended generally without careful experiment to find out the conditions in which it is likely to succeed.

(3) *Poultry Manure.*

The marked increase in the number of poultry in this country has brought into prominence an old question which has never yet been thoroughly examined : how does poultry manure compare with equivalent amounts of artificials ? In 1933 the Ministry of Agriculture set up a small committee to study this question, the experimental work to be done under the supervision of the Rothamsted staff. The manure was dried and prepared in a form in which it could

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be transported easily as a commercial product : the analysis of the samples ranged between the following limits :

	1933.	1934.
Moisture	5.8	8.4
Nitrogen (N)	3.6-4.4	2.6-3.3
Phosphoric oxide (P_2O_5)	2.9-4.0	3.2-3.8
Potash (K_2O)	1.6-1.9	1.6

The experiments were made with market garden crops as it seems probable that gardeners would make more use of poultry manure than farmers.

Comparison was made at a number of centres with equivalent mixtures of sulphate of ammonia, and superphosphate : the crops included potatoes, savoys, peas, sprouts, onions, and carrots. Pot culture experiments have been made at Rothamsted with spinach beet.

The general result both in 1933 and 1934 is that poultry manure in its first year is less effective than sulphate of ammonia ; little evidènce could be found that it is ever superior. At a number of centres neither manure was effective : apparently the ground was already in such high condition that even nitrogen failed to act.

The average results for potatoes at the 13 centres in which 3 cwt. per acre sulphate of ammonia was compared with the equivalent amount of poultry manure (approximately 1 ton) were as follows :

Potatoes, tons per acre. Mean of 13 *experiments.* 1934.

No Nitrogen	8.17
Poultry Manure 0.6 cwt. Nitrogen per acre	8.83
Sulphate of Ammonia, 0.6 cwt. Nitrogen per acre	9.53
Poultry Manure + Sulphate of Ammonia (1.2 cwt. N in all) ..	9.53
Mean	9.02
Standard error	±0.132

The return for the nitrogen is less than usual, being only about 9 cwt. potatoes per cwt. sulphate of ammonia. At some centres some crops gave more marked returns for nitrogen but again the sulphate of ammonia was never below and usually definitely superior to the poultry manure ; two examples are :

	No Nitrogen.	Poultry Manure.	Sulphate of Ammonia.	Standard Errors.
Newport, Salop, Savoys, tons	15.8	19.8	23.2	±0.896
Avoncroft, Worcester, Peas, cwt.	76.9	75.7	80.9	±1.66

There was no evidence that the poultry manure fortified the effect of the sulphate of ammonia ; indeed the average response to poultry manure was less in the presence than in the absence of sulphate of ammonia.

On the other hand there was some evidence of cumulative effect of poultry manure ; a dressing given in 1934 to land which had also received it in 1933 was more effective than sulphate of ammonia and the action seemed to be due to the nitrogen since phosphate caused but little increase :

Potatoes : 1934 (2nd Year of Application), tons per acre. Potton, Bedfordshire.

Mean Yield, 5.94.

Average increase due to Sulphate of Ammonia	0.82
,, ,, ,, ,, Superphosphate	0.24
,, ,, ,, ,, Poultry Manure	1.30
Standard error of increase	±0.113

GRASSLAND INVESTIGATIONS

The additional land purchased with the farm includes some 80 acres of grassland not hitherto in our occupation : it is very well suited to experiment,and schemes will be worked out in due course.

Basic Slag Investigations. The work on basic slag conducted under the aegis of the Basic Slag Committee of the Ministry of Agriculture was greatly extended in 1934, by the inclusion of experiments to test the new medium soluble slags produced by the steel manufacturers. These slags are not necessarily mixtures of high and low soluble slag : some of them contain new compounds recognisable by their crystals.

During 1934, a series of trials was conducted on swedes in Scotland by local workers in conjunction with Prof. McArthur and Rothamsted. In these experiments low soluble slags gave much better results than had been obtained in the earlier grassland experiments in England, but in all cases the effectiveness of the slag increased regularly with increasing solubility by the citric acid test. Medium soluble slags were intermediate between high and low soluble slags, but the experiments must continue for some years before their value can be properly assessed.

OTHER FODDER CROPS

The quality of green fodder crops has been for some time under preliminary investigation and now that the barley investigations have been transferred it will be further studied. The chemical work is being done by Dr. Norman and is based on the fact that a green fodder plant passes through two stages in its life history : in the first stage it is assimilating nitrogen and mineral matter from the soil and is consequently rich in protein equivalent and minerals : in the second stage it is elaborating carbohydrates, sugar, starch, cellulose, lignin, etc., and is consequently rich in starch equivalent and fibre. The work promises important practical application in several directions, including animal nutrition. Studies of " crude fibre " have shown its relation to the cell wall constituents. It is recognised, however, that chemical investigations alone will not satisfactorily deal with quality of fodder crops, since biochemistry is not yet sufficiently advanced to give complete indications of the feeding quality of the various crops ; methods have therefore been developed for using pigs for this purpose, adopting weight, grade and bacon factory reports as the criteria. The work is now reaching a stage where plant nutrition begins to approach animal nutrition, and it will shortly be necessary to invite the co-operation of investigators in animal nutrition.

LUCERNE

Prof. Southworth has continued his efforts to isolate strains of lucerne having a higher seed-yielding capacity than the named varieties at present in commercial use.

The season of 1934 being exceptionally sunny and warm the conditions were again favourable for the production of lucerne seed.

The following table shows the average seed yield at Woburn from the six family selections A.B.C.D.E.F. and the numbers of individual plants tested in each family group for the seasons 1933-34.

Family selection group.	Numbers of plants harvested. 1933.	1934.	Average weight of seed produced from each family. 1933.	1934.	Average for two years.
			grams.	grams.	grams.
A. Provence	9	17	18.09	22.90	20.49
B. 33-185	15	15	18.40	21.71	20.05
C. 32-50	2	5	29.70	27.92	28.81
D. 32-33	16	24	26.86	21.52	24.19
E. 13-1	10	14	26.81	28.50	27.65
F. 24-26	12	13	11.74	10.68	11.21

A. Provence from commercial seed. B, C, D, E, F, progeny of hybrid selections.

Maize and Soya Beans at Woburn. Certain Manitoba varieties grew and ripened successfully, producing good well-matured seed. These experiments are to be extended.

PLANT PATHOLOGY DEPARTMENT

MYCOLOGY

Mr. G. Samuel, the successor to Dr. Stoughton, began his work at Rothamsted by making a survey of the fungus diseases situation. He has shown that a kind of antagonism exists between certain groups of soil fungi so that one cannot develop when the other is present. This suggests possibilities of controlling pathogenic soil fungi that will be further studied. Meanwhile an interesting side line has been opened up : some of the actinomycetes picked out from the soil have the power of making fragrant perfumes. As the subject lies outside our purview it is being studied by a well-known manufacturer of scents and perfumes. This same expert found among the by-products of the milk effluent investigations a substance which we had been seeking to destroy but which he regards as of considerable potential value as a means of enhancing scents. Truly it is impossible for anyone to know where a scientific investigation may lead.

VIRUS DISEASES

When the Imperial Agricultural Conference of 1927 recommended that a central station should be set up at Rothamsted for research on virus diseases, it was recognised that their control would best be achieved by a study of the viruses themselves. It was realised that if the pathogenic viruses were living entities their mode of life must be something different from that of a bacterium or fungus, and no satisfactory treatment could be devised without an adequate understanding of their nature and the conditions of their activity. The work at Rothamsted accordingly was designed by Dr. Henderson Smith and the staff of his department for more general study of viruses rather than the specialised investigation of the individual disease and the individual crop, and the research now in progress continues to bear this character. Particular diseases are studied in detail from time to time as occasion demands, *e.g.*, the aucuba disease of the tomato, the virus diseases of *Hyoscyamus*, but always with the object of furthering the more general research.

The precise nature of a virus is still uncertain, and the work continues to probe deeper into this question. It has been shown that the virus is almost certainly particulate, and not diffused throughout the liquids in which it is found, that it is of a definite size which remains the same, independent of the host from which it is taken, and that different viruses are of different sizes. The virus could not be obtained wholly free from nitrogen nor could we substantiate the statement that it is crystallisable ; we have, in common with all other virus workers, failed to obtain multiplication in the absence of living cells, and have produced some evidence that it is not, at least in the case of one virus investigated, an invisible stage in the life history of a visible bacterium. Its physical and chemical properties, its behaviour under enzyme and photodynamic action, and other characters have been studied. The discovery in America of the local lesion technique has greatly facilitated examination, but this technique is itself not so straightforward and simple as it seemed at one time, and its results are largely dependent on the previous history of the inoculated plant. All these questions are still under examination, and are taken up again and again as further knowledge suggests possibly fruitful lines of attack. At present our position is that it is difficult to deny the living character of viruses, but their extremely small size, approaching molecular dimensions, suggests that they are alive only in the limited sense in which a gene is alive, and that they are incapable of independent existence.

Their relation to the living plants in which they are found has been, and is being, studied in great detail. During the last few years virus research everywhere has passed out of the descriptive stage, in which an account of the symptom-syndrome of a disease was considered sufficient, into a stage that is much more analytic ; and the generalisations of the earlier period are found to be inaccurate. It has been shown here, and is now generally believed, that a virus disease is not necessarily a general systemic disease, as was at one time thought, but may be localised within the infected plant to definite circumscribed areas, in which the virus multiplies. The mode of movement of the virus within the plant was considerably clarified when it was shown here, for the first time, that virus did not travel in the water-stream, as had always previously been assumed, but was associated with living tissue only. There is still scope for much work to be done on this subject, and on the methods of infection and the factors which influence success or failure in inoculation. The effect of viruses on the metabolism of the infected plant, with which is bound up their symptomatology and the damage they inflict, has been and is being studied. A recent development, of which the further outcome cannot yet be foreseen, is the discovery that a plant inoculated with one strain, possibly of low virulence, of a given virus is protected against later inoculation with a second, possibly more virulent, strain of the same virus. The occurrence of strains differing from one another in one or more respects is coming into more and more prominence, and it seems certain that such strains may arise in nature as well as in response to artificial treatment. These questions have occupied us during the past year, and will continue to do so in the immediate future ; and some preliminary work has been done on the introduction of serological methods into our plant virus research.

The intimate changes which the presence of virus produces within a cell have received much attention in the Department in recent years. The demonstration that the intracellular inclusions, which were long regarded as characteristic of the presence of virus, are not a stage in the life history of the virus but are in the main a reaction of the cell-components to the virus, a demonstration which had been based on direct observation of the changes occurring in the infected cell, has been strikingly confirmed by the further proof that it is possible by chemical agents, *e.g.*, molybdic acid, to induce the formation of similar inclusions in the absence of virus. The conditions which control this formation of inclusion-bodies are still obscure, and we have been endeavouring by micro-manipulation and micro-dissection methods to study the changes induced inside the cell on virus introduction. This is a highly skilled and difficult technique, which is not yet fully perfected, but it ought to add considerably to our knowledge of what occurs within the cell as the consequence of the entry of the virus particles.

The fact that in nature virus is mainly transmitted from plant to plant by the agency of insects has led to much laborious work within the Department. The determination of the insects mainly responsible for dissemination of the viruses studied here is comparatively straightforward, though the fact that the vector for one of the commonest of our potato-virus diseases is still unidentified shows that the task is not always easy. But there are many problems still unsolved which deal with the mechanism of the transference from plant to plant, and the behaviour of the virus within the insect. It is generally assumed that the virus is introduced into the plant with the saliva of the infecting insect ; but it is not clear how the virus reaches the saliva, what interferes with it in those insects which do not function as vectors, nor why one insect can carry while another of similar habit does not. It is evident that the quantities of juice must be very small indeed which can be taken into the alimentary canal through the tiny stylets of, say, an aphid in the few minutes sufficient to infect the insect, and we have tried to obtain some idea of the quantities involved. Three methods were used, including feeding the insects on radio-active material, whose presence in minute quantity can be measured ; and the results are in fair concordance. The amount is so small as practically to demonstrate that multiplication must occur within the insect in those cases where the insect remains infective throughout its life after a single short period of feeding on the infected plant. We have tried throughout to introduce into our entomological work quantitative methods, and an extensive study, still in progress, has been made of the quantitative relations between number of insects, time of feeding, and resultant infection. To obtain results statistically valid, this involves a very large number of plants and much replication, but it has already led to the detection of a marked seasonal variation in the infectivity of the insects used, and will itself place on a firm foundation much that is commonly accepted on rather uncertain evidence.

ENTOMOLOGY

The work of 1934 was mainly concerned with studies of the factors determining the fluctuations and migrations of insect populations. It involves taking frequently and systematically a census of the populations of insects concerned and methods of doing this have been worked out. The results are then correlated with climatic factors, and, for the night flying insects, with moonlight and cloudiness of the

https://doi.org/10.23637/ERADOC-1-66

sky: of all these factors temperature appears to be the most important. Dr. Barnes continued his work on gall midges and Mr. H. C. F. Newton carried a stage further his observations on the ovipositional and feeding reactions of the sawfly *Pteronidea melanaspis*.

The investigations on bees made during the last eleven years by Mr. D. T. M. Morland have attracted more and more attention from practical beekeepers and last year the British Bee Keepers Association guaranteed the sum of £250 annually for a period of three years, to which the Agricultural Research Council adds another £250, to permit of the investigation of Brood diseases. Dr. H. L. Tarr was appointed to the work and began on May 1st, 1934. The Lister Institute of Preventive Medicine is kindly allowing Dr. Tarr the use of their laboratories for the serological and other investigations thereby saving considerable reduplication of costly equipment and ensuring adequate control on the bacteriological side. A very successful conference with practical beekeepers was held in May, 1934, in which their experience was freely set out for the benefit of the investigators. This led to a request for further conferences and a further one was held in May, 1935, on swarming, a subject on which Mr. Morland has been working for the past few years and has now accumulated a mass of valuable information. Some 350 persons attended this Meeting and as no hall could be had to hold them, a marquee had to be erected.

INSECTICIDES

Drs. Tattersfield and Martin are studying further improvements in the method of the chemical evaluation of samples of pyrethrum, and they have begun a parallel investigation on derris. The results so far obtained have attracted wide interest and Dr. Tattersfield has been invited to the United States to confer with American experts on the subject.

Owing to shortage of staff the work on soil insecticides and fumigants has been in abeyance for a few years but this is now resumed, thanks to a grant from Imperial Chemical Industries, and Mr. W. R. S. Ladell has been appointed in charge.

STATISTICAL DEPARTMENT

Much of the time of this department is occupied with the design and analysis of replicated experiments at Rothamsted, Woburn and elsewhere and this work continues to expand as shown by the following table:

	Number of Experiments			*Plot Yields Analysed*		
Year.	Rothamsted and Woburn.	Outside Centres.	Total.	Rothamsted and Woburn.	Outside Centres.	Total.
1925	8	—	8	328	—	328
1926	13	4	17	740	73	813
1927	12	5	17	802	150	952
1928	11	12	23	1,267	392	1,659
1929	12	12	24	1,565	352	1,[illegible]17
1930	14	24	36	1,341	918	2,259
1931	13	41	52	2,044	1,968	4,012
1932	17	49	64	2,153	3,792	5,945
1933	15	78	93	2,539	4,870	7,409
1934	17	98	115	2,060	7,082	9,142

In addition a considerable amount of assistance is given to agricultural experimenters from overseas. Some send or bring their proposals for field experiments so as to ensure good design, others bring their accumulated data for help in extracting all the valid information they can be made to yield. There is a growing demand for this kind of help and it is hoped that permanent provision may be made for it.

As special pieces of work during the year Mr. Yates has studied the applicability of the χ^2 test to contingency tables, especially 2 x 2 tables, involving small numbers, while he and Mr. Cochran both devoted considerable time to the study of the Woburn data. This Report is now complete and is being prepared for the press.

THE CONTRIBUTION OF ROTHAMSTED TO SOIL PHYSICS

B. A. Keen

Until 1913 no systematic work on the physical properties of soil had been done at Rothamsted or indeed in Great Britain. The investigations were suspended during the War and resumed in 1919. Most of the publications of the Physical Department fall conveniently into a few groups, and these have been utilised, rather than a chronological order of papers, in the short account that follows. A full discussion will be found in the Rothamsted Monograph entitled "The Physical Properties of the Soil."

Mechanical Analysis

The methods of mechanical analysis have been developed in two main directions : existing methods based on the separation into a few groups or fractions have been improved both in simplicity and accuracy ; and much attention has been paid to the elegant procedure, first evolved by Odén in Sweden, by which a particle size distribution curve is obtained.

In Great Britain a co-operative investigation was organised from Rothamsted to test the suitability of two important improvements devised by Robinson of Bangor, Wales : pre-treatment of the sample with hydrogen peroxide to remove organic matter, and the substitution of pipette sampling for separation by sedimentation. Two reports[1] were issued, recommending for official adoption in Great Britain the use of hydrogen peroxide in the pre-treatment of the sample, and the employment of the pipette for determining the percentage of the silt and clay fractions. The new method was subsequently adopted, with a minor modification, as the Official Method A, of the International Society of Soil Science. Thus, the International and British methods of mechanical analysis are identical, except for one minor difference. In changing their method, British workers were faced with many difficulties in preserving continuity with the extensive results accumulated by the older methods ; but the international character of soil science, and the ultimate advantages of a generally accepted universal method, were

(1) A Sub-Committee of the Agricultural Education Association—"The Mechanical Analysis of Soils : a Report on the Present Position, and Recommendations for a New Official Method." J. Agric. Sci., 1926, Vol. XVI, pp. 123-144 ; "The Revised Official British Method for Mechanical Analysis." J. Agric. Sci., 1928, Vol. XVIII, pp. 734-739. See also "The Official Method for the Mechanical Analysis of Soils Adopted by the Agricultural Education Association in 1925." Agric. Progress, 1926, Vol. III, pp. 106-110 ; and "Revised Official Method for the Mechanical Analysis of Soils Adopted by the Agricultural Education Association in 1927." Agric. Progress, 1928, Vol. V. pp. 137-144.

considered to have over-riding importance. An appeal [2] was made to all soil workers to take similar action, with little or no effect.

In the International and British methods, as in many others, a fine mesh wire gauze sieve is used to separate the coarse sand. The gauze stretches gradually with use, and the originally plane surface becomes bowl-shaped ; in addition the warp and weft wires undergo relative movements which produce mesh apertures both larger and smaller than the original ones. A mathematical and experimental examination of these two factors showed that no serious error was probable until the sieve had become badly worn.

Odén's method is based on the measurement of the progressively changing density or hydrostatic pressure during the sedimentation of a suspension. The particles settle on a pan immersed in the suspension, and the increase in weight is recorded at intervals. Evidently it is desirable that these intervals should be as short as possible : in other words, the balance should be automatic and continuous recording. A balance fulfilling these requirements was developed [3] by the Physical Department at Odén's suggestion. An apparatus which gives a continuous record of weight changes has, of course, uses beyond mechanical analysis ; this was demonstrated in an interesting way during the final trials of the apparatus, when a discontinuity in the dehydration of certain salt hydrates was discovered. [4] Further work with the apparatus in an attempt to eliminate a discrepancy between the calculated and actual final weight caught by the pan, led to the disconcerting discovery of an inherent defect in the Odén procedure [5] and, indeed, in every other method of obtaining size distribution curves. The error arises because any attempt to measure changes of density or hydrostatic pressure in a sedimenting suspension is bound to disturb in a complex fashion the very factor it is desired to measure. Thus, in Odén's method, the pan shields the liquid below it from the descent of particles, while the liquid in the annular space around the pan is not so shielded, and a density difference is set up between them. Interchange of suspension between these two regions inevitably occurs, which interferes with the free vertical fall of the particles and destroys the fundamental assumption on which the mathematical analysis is based. Many experiments were made in the hope of removing the trouble, or at least of reducing it to a systematic error, without success. Although this seriously limits the use of these methods for purposes of research, they are useful for specifying rapidly the approximate mechanical analysis of a soil. An exceedingly convenient and quick method has been devised [6] which gives, in effect, the time-rate of change of the excess density of the suspension at a given fixed point. The readings of the manometer

(2) B. A. Keen—"Mechanical Analysis: National and International." Soil Research, 1928 Vol. I, pp. 43-49.

(3) J. R. H. Coutts, E. M. Crowther, B. A. Keen, and S. Odén—"An Automatic and Continuous Recording Balance. (The Odén-Keen Balance.)" Proc. Roy. Soc., A, 1924, Vol. CVI, pp. 33-51.

(4) E. M. Crowther and J. R. H. Coutts—"A Discontinuity in the Dehydration of Certain Salt Hydrates." Proc. Roy. Soc., A, 1924, Vol. CVI, pp. 215-222.

(5) J. R. H. Coutts and E. M. Crowther—"A Source of Error in the Mechanical Analysis of Sediments by Continuous Weighing." Trans. Faraday Soc., 1925, Vol. XXI, pp. 374-380.

(6) E. M. Crowther—"The Direct Determination of Distribution Curves of Particle Size in Suspensions." J. Soc. Chem. Ind., 1927, Vol. XLVI, pp. 105T-107T. E. M. Crowther—"A Manometric Apparatus for the Direct Determination of Summation Percentage Curves in Mechanical Analysis." Proc. First Internat. Cong. Soil Sci., 1927, Vol. I, pp. 394-398.

are then directly proportional to the summation curve, and only one differentiation is needed to obtain the distribution curve instead of two, as in Odén's method. The apparatus is particularly suitable for giving summation curves for the coarser fractions of soils, and for sandy soils, and is apparently accurate to within 2-3 per cent.

SOIL REACTION

There is no sharp boundary between physico-chemical and physical properties of soils, and the Department has therefore examined certain physico-chemical aspects of the subject. After a preliminary investigation of colorimetric methods ([7]), the electrometric method was taken in hand ; the important technical problem of designing a satisfactory hydrogen electrode vessel for *p*H measurements of soil suspensions was solved([8]), and the apparatus was used in a series of investigations. The relations between *p*H, buffer action, the effects of electrolytes and lime requirements were clarified. The unique series of classical experimental plots at Rothamsted and Woburn was examined and the changes in *p*H produced by the long continued applications of various manures was determined ; one conclusion of practical importance was that the changes in *p*H value as a result of applying lime to the soil is less than that shown in the laboratory owing in part to the subsoil acidity.([9]) A detailed study of the depth distribution of reaction([10]) on the classical plots showed that changes of reaction in the surface layer affected the lower depths to at least 36 inches. These depth changes in *p*H were also associated with marked differences in soil texture, which are not, however, a simple function of the *p*H. The top soil, although the most acid, showed no flocculation, probably owing to the protective action of the humus colloids ; the 4½-9 inch depths showed distinct flocculation but the suspension remained turbid ; the lower depths flocculated completely and immediately, possibly owing to the accumulation of calcium and aluminium ions leached down from the very acid surface layer. These textural differences will affect air and water movement within the soil ; they are important indirect factors in the relationship between soil reaction and crop growth.

In practice, the amount of lime needed to correct soil acidity is usually determined by one or other of numerous "lime-requirement" methods which, on different soils and in the hands of different workers may give widely varying results. The well-known Hutchinson-MacLennan method, which measures the interaction of soil with a calcium bicarbonate solution saturated with carbon-dioxide, was shown ([11]) to underestimate the amount of lime needed to produce a neutral soil, and the value obtained depended on the amounts of soil

(7) E. A. Fisher—" Studies on Soil Reaction. I. A Résumé. II. The Colorimetric Determination of the Hydrogen Ion Concentration in Soils and Aqueous Soil Extracts. (Preliminary Communication.) " J. Agric. Sci., 1921, Vol. XI, pp. 19-65.

(8) E. M. Crowther—" Studies on Soil Reaction. III. The Determination of the Hydrogen Ion Concentration of Soil Suspensions by Means of the Hydrogen Electrode." J. Agric. Sci., 1925, Vol. XV, pp. 201-221.

(9) E. M. Crowther—" Studies on Soil Reaction. IV. The Soil Reaction of Continuously Manured Plots at Rothamsted and Woburn." J. Agric. Sci., 1925, Vol. XV, pp. 222-231.

(10) E. M. Crowther—" Studies on Soil Reaction. V. The Depth-Distribution of Reaction and Flocculation in Continuously Manured Soils." J. Agric. Sci., 1925, Vol. XV, pp. 232-236.

(11) E. M. Crowther and W. S. Martin—" Studies on Soil Reaction. VI. The Interaction of Acid Soils, Calcium Carbonate and Water, in Relation to the Determination of ' Lime Requirements.' " J. Agric. Sci., 1925, Vol. XV, pp. 237-255.

https://doi.org/10.23637/ERADOC-1-66

and of calcium bicarbonate solution used, owing to the buffer action of the soil. Indirect titration curves derived from these results diverged systematically from direct electrometric titration curves because of the variable calcium concentration of the final bicarbonate solutions. The " lime-requirement," therefore, should be obtained by interpolation to some agreed arbitrary concentration. The inconvenience of making several separate measurements to obtain the curve was avoided by the discovery of an empirical relationship which enables the interpolation to be made from a simple determination. Recently, a new method has been devised ([12]) for assessing the lime-status of a soil, which should prove very useful owing to its rapidity and simplicity. The organic acid, *p*-nitrophenol, is half neutralised by lime water ; the *p*H is then close to 7. When soil is added lime will be abstracted from or supplied to the solution, depending on whether the soil was originally more acid or more alkaline than the solution. If this quantity of lime is not large compared with the total lime in the solution, the *p*H of the solution remains close to 7. Simple titrations of the filtered and original solutions are made, from which is calculated the quantity of lime that must be given to or taken from the soil to bring it to neutrality. Other *p*H values can be used by employing different acids which, like *p*-nitrophenol, have soluble calcium salts, and the range can be further widened by increasing their concentration. A buffer-curve for a soil can therefore be traced in detail, since lime is the principal exchangeable base in normal soils. ([13]) The individual points on the curve can be determined by an electrical conductivity or, if the widest range of *p*H is needed, by titration. Both methods are rapid and simple, the former being especially so. Examination by these means of soils of different types, and of plots that have received markedly different manuring, shows that the form of the curves will throw much light on soil differences and soil genesis, as the curves for different soil samples show both marked similarities and differences. For example, the partial buffer capacity at *p*H 7—which can rapidly be measured by the change in electrical conductivity produced when soils are put into a mixture of 0.1 molar K_2HPO_4 and 0.05 molar KH_2PO_4 ([14])—is closely correlated with other physical characteristics of the soils, such as the heat of wetting, and the moisture content at 50 per cent. relative humidity (See p. 43).

Plastic Behaviour of Soil and Clay

The Department has given much attention to this subject. A wide range of moisture content has been used, giving all stages of consistency of the soil, or clay, between plastic behaviour (c.f., modelling clay) and quite thin pastes. Special interest attaches to the latter as, in addition to its intrinsic importance as a problem in a neglected field of pure physics, it offers a means of studying the colloidal properties of clay particles over a range of moisture content in which

(12) R. K. Schofield—" Rapid Methods of Examining Soils. II. The Use of *p*-Nitrophenol for Assessing Lime Status." J. Agric. Sci., 1933, Vol. XXIII, pp. 252-254.

(13) R. K. Schofield—" Note on the Usefulness of Buffer Capacity in Soil Examination." Trans. Sixth Comm. Internat. Soc. Soil Sci., 1933, Vol. B, pp. 80-84.

(14) R. K. Schofield—" Rapid Methods of Examining Soils. III. The Use of Dihydrogen Potassium Phosphate in Studying Base Exchange Capacity." J. Agric. Sci., 1933, Vol. XXIII, pp. 255-260.

both solid and fluid (or viscous) properties are displayed ; in field conditions, of course, the former only is predominant.

In the ceramic and allied industries, a number of measurements, more or less empirical, have long been used to specify the clays at different stages of their preparation. Preliminary examination of the behaviour of clay and soil pastes showed that improvement, both in the theory, and in the design of suitable apparatus, was badly needed before progress could be made. A series of papers (15) describes the development of the theory and the experimental results obtained with a specially devised plastometer and flowmeter.

Examination of the flow curve when the stress is progressively increased from zero to a value which is still below that producing turbulent flow, shows that four stages can be recognised. Stage I, no flow until a critical shearing stress is reached—the paste remains immovable. Stage II, plug flow—the paste moves like a solid rod in the capillary tube. This agrees mathematically with the hypothesis that the plug is sliding through a very thin layer of " liquid " of constant thickness, probably hydration envelopes of the outermost particles modified by the proximity of the capillary wall. Stage III, mixed flow—a complex range which can be qualitatively described as a central plug moving through a sheath of paste that approximates to streamline flow. As the stress is increased, the diameter of the central plug progressively diminishes. Stage IV, pseudo-streamline flow, as for a truly viscous fluid, with the restriction that the properties of the clay paste are modified in the annular region near the wall of the capillary tube. In effect, the consistency of the paste in this region is lowered ; the cause is not yet understood, but experiment shows it is not due to orientation of laminar particles in the direction of flow, nor to a decrease of concentration as compared with the paste in the centre portion of the capillary. This modification must not be confused with the layer of hydration envelopes described in stage II. This stage is inhibited if the inside of the tube is previously lightly etched, whereas stage IV is unaffected.

This work has a most important bearing on the extensive studies of other workers on " structure viscosity " and " structure turbulence." There is some obscurity of meaning in these terms, and no simple relationship has yet been demonstrated between the properties they are supposed to describe. Nevertheless, if they exist, our work shows that their effects must cancel each other exactly in all the hundreds of soil and clay pastes we have investigated over a wide range of stress. (16) This is so improbable, that it raises grave doubts as to the reality of " structure turbulence " and " structure viscosity" in soil and clay pastes, and indeed, in other systems.

The value of the above work on soil pastes is to provide a link

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(15) G. W. Scott Blair and E. M. Crowther—" The Flow of Clay Pastes through Narrow Tubes." J. Phys. Chem., 1929, Vol. XXXIII, pp. 321-330 ; R. K. Schofield and G. W. Scott Blair—" The Influence of the Proximity of a Solid Wall on the Consistency of Viscous and Plastic Materials." J. Phys. Chem., 1930, Vol. XXXIV, pp. 248-262 ; G W. Scott Blair—" A Further Study of the Influence of the Proximity of a Solid Wall on the Consistency of Viscous and Plastic Materials." J. Phys. Chem., 1930, Vol. XXXIV, pp. 1505-1508 ; R. K. Schofield and G. W. Scott Blair—" The Influence of the Proximity of a Solid Wall on the Consistency of Viscous and Plastic Materials. III." See also G. W. Scott Blair—" The Rheology of Soil Pastes." J. Rheology, 1930, Vol. I, pp. 127-138 ; and R. K. Schofield—" Simple Derivations of Some Important Relationships in Capillary Flow." Physics, 1933, Vol. IV, pp. 122-128.

(16) G. W. Scott Blair—" Ueber die Geschwindigkeitsfunktion der Viskosität disperser Systeme." Koll. Zeits., 1929, Vol. XLVII pp. 76-81 ; Vol. XLVIII, p. 283.

https://doi.org/10.23637/ERADOC-1-66

between the extreme condition represented by soil in the field and the weak suspensions used for flocculation and sedimentation studies and in mechanical analysis, and to show, in a fresh aspect, certain familiar properties of soil.(17) A number of examples follow. The behaviour of soil and clay pastes depends on their previous history: a paste made from soil that has been dried does not show the plug-flow of stage II. The variations in the resistance to the plough over a field are closely correlated with the shearing strengths of pastes made from soil samples taken from that field. Since shearing strength is independent of rate of shear it follows that ploughing speed should not appreciably affect the resistance to ploughing—a fact that was observed in the dynamometer measurements. (See the section on Soil Cultivation.) Farmyard manure, and large dressings of chalk reduce the plough draft and also the shearing strength of the soil pastes. Changes in the elusive but fundamental soil property known as " tilth " can be studied by plastometric measurements on pastes made from samples taken at suitable times during the year.

Finally, at the request of the International Society of Soil Science a report has been drawn up containing recommendations for standardising the use and meaning of the numerous terms employed in this subject in the English, French, German and Russian languages.(18)

Behaviour of other soft materials.—The work on clay which behaves predominantly as a plastic material, was extended to another substance which shows both plastic and elastic properties. Flour dough was selected for study, as this material has considerable elasticity and a high degree of plasticity, and it was anticipated that the result would be of interest to the milling and baking industries. For this reason the technological aspects were investigated jointly with the Research Association of British Flour Millers. Theoretical and laboratory studies of dough have been made(19), in addition to an extensive study of the baking qualities of flours in relation to their behaviour in the laboratory tests. An important feature of the work is that dough shows a phenomenon similar to the work-hardening of metals, since the time of relaxation and the viscosity for a given stress depend on the total deformation; two further properties, well known in the study of metals, are also present : elastic after-effect and elastic hysteresis.

RELATIONS BETWEEN SOIL AND ITS WATER CONTENT

The classification of soil moisture first adopted by earlier workers on soil physics recognised three main divisions : hygroscopic water, held so tightly to the soil particles as to be unavailable for plants ; capillary water, free to move under surface tension forces ; and gravitational water, which drained away because it was in excess of what the soil could hold. Although these terms were introduced

(17) B. A. Keen and G. W. Scott Blair—" Plastometric Studies of Soil and Clay Pastes." J. Agric. Sci., 1929, Vol. XIX, pp. 684-700 ; G. W. Scott Blair and F. Yates—" The Effect of Climatic Variations on the Plasticity of Soil." J. Agric. Sci., 1932, Vol. XXII, pp. 639-646 ; G. W. Scott Blair—" Consistency Constants of the Soil with Special Reference to Field Operations." Trans. Sixth Comm. Internat. Soc. Soil Sci., A, 1932, pp. 246-252.

(18) G. W. Scott Blair—" Definition and Translation of Rheological Terms used in Soil Physics." Trans. First Comm. Internat. Soc. Soil Sci., 1934, pp. 159-167.

(19) R. K. Schofield and G. W. Scott Blair.—" The Relationship between Viscosity, Elasticity and Plastic Strength of Soft Materials as Illustrated by some Mechnaical Properties of Flour Doughs." Proc. Roy. Soc., A, 1932, Vol. CXXXVIII, pp. 707-718 ; 1933, Vol. CXXXIX, pp. 557-566 ; 1934, Vol. CXLI, pp. 72-85.

purely as a convenient qualitative description, they acquired an air of reality, partly, no doubt, owing to the lack of adequate physical investigations on soil moisture relationships. The increasing attention paid in pure science to colloidal phenomena led to the recognition of colloidal properties in soil. The colloidal material has its origin in the clay and organic matter and, although little direct evidence was produced, it was considered to be distributed in a thin layer over the larger mineral particles as a kind of gel or emulsion coating. Many of the earlier experiments of the Department dealt with the possible effect of such a coating on the soil moisture relationships. ([20]) It was shown that the vapour pressure of moist soil was very close to that of free water until the soil moisture content had reached quite a low value. (See the remark on "hygroscopic coefficient," p.44.) It was concluded that over this range—which is at least equal to, and probably greater than, that on which plant roots can draw—the physical properties of the soil moisture were not appreciably different from that of free water; although later work([21]) suggests that an appreciable proportion of soil-water is held or imbibed by soil colloids, it is improbable that the association is the intimate one visualised by other workers who use the term 'bound-water,' which implies a profound change in its physical properties.

Attention was therefore turned to the moisture ranges defined as "capillary water" and "gravitational water" in the old classification, to see how far its behaviour could be interpreted by the simple laws of surface-tension over curved surfaces. ([22]) The ideal soil of equal sized spheres, arranged in regular packing, and free from colloidal material was employed in both the theoretical and practical studies. The important feature of these investigations was that attention was focussed on the geometry of the pore spaces in the ideal soil. The pore space is essentially cellular, and the cells communicate with one another through narrow necks. This structure imposes a quantum character on the moisture changes over a great part of the higher moisture range. The individual cell does not fill or empty by smooth reversible changes, but shows two unstable stages at which filling or emptying is completed at a bound. The movement into or out of the cell is controlled by the pressure-deficiency under the curved water meniscus and, owing to the geometry of the cells and their communicating necks, the pressure deficiency for a cell to empty (decreasing moisture content) has a higher value than that at which

(20) B. A. Keen—"The Relations Existing Between the Soil and its Water Content." J. Agric. Sci., 1920, Vol. X, pp. 44-71; "A Quantitative Relation Between Soil and the Soil Solution Brought out by Freezing-Point Determinations." J. Agric. Sci., 1919, Vol. IX, pp. 400-415; "The Evaporation of Water from Soil," J. Agric. Sci., 1914, Vol. VI, pp. 456-475; "The Evaporation of Water from Soil. II. Influence of Soil type and Manurial Treatment." J. Agric. Sci., 1921, Vol. XI, pp. 432-440; B. A. Keen, E. M. Crowther, and J. R. H. Coutts—"The Evaporation of Water from Soil. III. A Critical Study of the Technique." J. Agric. Sci., 1926, Vol. XVI, pp. 105-122; A. N. Puri, E. M. Crowther, and B. A. Keen—"The Relation between the Vapour Pressure and Water Content of Soils." J. Agric. Sci., 1925, Vol. XV, pp. 68-88; E. M. Crowther and A. N. Puri—"The Indirect Measurement of the Aqueous Vapour-Pressure of Capillary Systems by the Freezing-Point Depression of Benzene." Proc. Roy. Soc. A, 1924, Vol. CVI, pp. 232-242.

(21) E. W. Russell and R. S. Gupta—"On the Measurement of Imbibitional Water." J. Agric. Sci., 1934, Vol. XXIV, pp. 315-325.

(22) B. A. Keen—"On the Moisture Relationships in an Ideal Soil." J. Agric. Sci., 1924, Vol. XIV, pp. 170-177; W. B. Haines—"Studies in the Physical Properties of Soils. IV. A Further Contribution to the Theory of Capillary Phenomena in Soil." J. Agric. Sci., 1927, Vol. XVII, pp. 264-290; "Studies in the Physical Properties of Soil. V. The Hysteresis Effect in Capillary Properties and the Modes of Moisture Distribution Associated Therewith." J. Agric. Sci., 1930, Vol. XX, pp. 97-116; B. A. Keen—"A Note on the Capillary Rise of Water in Soils." J. Agric. Sci., 1919, Vol. IX, pp. 396-399; "The Limited Role of Capillarity in Supplying Water to Plant Roots." Proc. First Internat. Cong. Soil Sci., 1927, Vol. I, pp. 504-511.

https://doi.org/10.23637/ERADOC-1-66

it fills (increasing moisture content). Hence the graph connecting moisture content of the ideal soil with pressure deficiency shows a well marked hysteresis loop, one side of which corresponds to increasing moisture content, and the other to decreasing moisture content.

In natural soil the pore spaces are much more irregular, but the same considerations apply. The practical effect is that there is no unique value of moisture content associated with a given pressure deficiency : it will be one value if the soil moisture is decreasing, another if it is increasing. Hence the numerous attempts to measure soil moisture content *in situ*, by placing a porous pot in contact with the soil and observing the reading of an attached manometer have given conflicting results.

A further conclusion is that water can rise by capillary action in the soil only to a limited distance : in a heavy loam soil it will not exceed 3-4 feet and the rate of movement is exceedingly slow.

SOIL PROPERTIES CONCERNED IN CULTIVATION

The mechanical properties of soil likely to be of importance in cultivation have been discussed by numerous workers, and especially by Atterberg. Certain of his methods were re-examined in the Physical Department, in particular his cohesion test. Atterberg found abrupt changes in direction of the curves connecting cohesion and moisture content and used the position of these breaks for classifying the field behaviour of different soils. However, our experimental irregularities were too great to confirm the existence of the breaks, although soils of widely differing properties were employed.(23) The cohesion forces were ascribed in the main to the surface tension of the contained water in the minute interstices and points of contact of the soil grains,(24) and it appeared that the electrical resistance of soil blocks might throw light on the water distribution. Some preliminary measurements gave wide differences between different soils(25); later, a more elaborate investigation (26) showed that the nature of the electrode and the rate the blocks dried had considerable effect, but four characteristic breaks in the curve were found, two of which were readily identified, by separate experiments, with Atterberg's "Ausrollgrenze" (the lower plastic limit) and the "Schwindungsgrenze" (moisture content at which air enters the pores) while the two lower ones were hitherto unrecorded.

In work of this kind much confusion will arise unless the full difference between natural soil and the simplified "ideal" soil, consisting of equal sized spheres, uniformly packed and free from colloidal material is very clearly kept in mind. The volume shrinkage of moist soil blocks as drying proceeds takes place in two stages. At first the volume shrinkage is exactly equal to the volume of water evaporated, but later, as the grains come closer

(23) W. B. Haines—"Studies in the Physical Properties of Soils. I. Mechanical Properties Concerned in Cultivation." J. Agric, Sci. ,1925, Vol. XV, pp. 178-200.
(24) W. B. Haines—"Studies in the Physical Properties of Soils. II. A Note on the Cohesion Developed by Capillary Forces in an Ideal Soil." J. Agric. Sci., 1925, Vol. XV, pp. 529-535.
(25) W. B. Haines—"Studies in the Physical Properties of Soils. III. Observations on the Electrical Conductivity of Soils." J. Agric. Sci., 1925, Vol. XV, pp. 536-543.
(26) G. H. Cashen—"Measurements of the Electrical Capacity and Conductivity of Soil Blocks' J. Agric. Sci., 1932, Vol. XXII, pp. 145-164.

together, the shrinkage is smaller, although still linear. In the case of materials that are free from a colloidal or gel-like coating[27] this second stage is absent, and no warping occurs in the later stages fo drying, and differential stresses which lead to rupture of the blocks on remoistening are absent. In the case of natural soils, however, such stresses are instrumental in the disintegration by weather of the large lumps of soil left by autumn ploughing.

" *Single value* " *measurements.*—Attempts by many workers have been made to assess the general character of a soil by measuring one property, or group of properties, thus specifying the soil by a single number (or " single value ") in place of the group of figures given by a mechanical analysis. The underlying idea is that such a " single value " would place the soils in an order that closely reflects their field behaviour. The Physical Department has given much attention to this problem[28] and has tested many of the suggested methods on a wide range of soils. The methods were chosen as far as possible from those requiring only simple apparatus. The measurements were repeated after the soils had been treated with hydrogen peroxide, to obtain some idea of the contribution of organic matter to the result. A preliminary examination showed that certain methods gave highly correlated results, presumably because they were measuring the same, or closely related physical properties. At a later stage, a full statistical examination was carried out on extensive data for Natal soils, obtained in Mr. J. R. H. Coutts' experiments. It was shown that from a knowledge of the base exchange capacity of the soil, a good prediction could be made of the sticky point, the moisture content at 50 per cent. relative humidity, and the weight of water held by the saturated soil ; the clay content, on the other hand, was of minor importance in predicting these properties but, in conjunction with the silt content, it was closely related to the xylene equivalent. The xylene equivalent—which is obtained by using xylene in the moisture equivalent apparatus instead of water—is of interest : it measures a soil property that is independent of the organic matter present, for it can be almost completely predicted from other measurements made on the soil after treatment with hydrogen peroxide. The net result of the statistical examination of this series of Natal soils was to show that certain single-value measurements were controlled by the base exchange capacity, while others depended more on the content of clay and silt. How far this

(27) W. B. Haines—" The Volume-Changes Associated with Variations of Water Content in Soil." J. Agric. Sci., 1923, Vol. XIII, pp. 296-310.

(28) B. A. Keen and H. Raczkowski—" The Relation between the Clay Content and Certain Physical Properties of a Soil." J. Agric. Sci., 1921, Vol. XI, pp. 441-449 ; B. A. Keen and J. R. H. Coutts—" 'Single Value' Soil Properties : A Study of the Significance of Certain Soil Constants." J. Agric. Sci., 1928, Vol. XVIII, pp. 740-765 ; B. A. Keen—" 'Single Value' Soil Properties : a Study of the Significance of Certain Soil Constants. IV. A Further Note on the Technique of the 'Box' Experiment." J. Agric. Sci., 1930, Vol. XX, pp. 414-416 ; J. R. H. Coutts—" 'Single Value' Soil Properties : a Study of the Significance of Certain Soil Constants. VII. The Moisture Equivalent and Some Related Quantities." J. Agric. Sci., 1932, Vol. XXII, pp. 203-211 ; E. W. Russell—" The Significance of Certain 'Single Value' Soil Constants." J. Agric. Sci., 1933, Vol. XXIII, pp. 261-310 ; H. Janert—" The Application of Heat of Wetting Measurements to Soil Research Problems." J. Agric. Sci., 1934, Vol. XXIV, pp. 136-150 ; A. N. Puri—"A Critical Study of the Hygroscopic Coefficient of Soil." J. Agric, Sci., 1925, Vol. XXV, pp. 272-283 ; A. Sen and C. H. Wright—" The Electrical Conductivity of Aqueous Soil Suspensions as a Measure of Soil Fertility." J. Agric. Sci., 1931, Vol. XXI, pp. 1-13 ; A. Sen—" The Measurement of Electrica Conductivity of Aqueous Soil Suspension and its Use in Soil Fertility Studies." J. Agric. Sci., 1932, Vol. XXII, pp. 212-234 ; B. A. Keen—" Physical Measurements of Soil in Relation to Soil Type and Fertility." Emp. Cotton Growing Corporation Conference, July, 1934 ; J. M. Albareda—" Caracterización de Suelos Tropicales y Sub-Tropicales Mediante Determinaciones Físicas y Físicoquimicas." " Sobre la Fertilidad de Algunos Suelos Tropicales." Publicado en la Revista de la Acad. de Ciencias, de Madrid, 1934, Vol. XXXI, pp. 320-350, 457-514, and 515-519.

generalisation may apply to a wider range of soil types is uncertain. Some departure is to be expected ; for example, the loss on ignition of the natural and peroxide treated soils of the Natal series gave results of no great importance, whereas the inherent fertility of a series of Malayan rubber soils was reasonably well predicted by the ignition loss of the soils and of the clay fractions.

The relationships become more diffuse when single-value measurements are considered as an aid in distinguishing one soil type from another. Ideally, one would desire to obtain very good correlation between two different measurements when done on soils from the same type and to find that the regression constants of the curve connecting these two measurements varied with the soil type. Up to the present it appears that within a broad soil-type the sub-types are sufficiently variable to affect the correlation between the measurements ; it may, therefore, be that a soil type will not be characterised by regression constants of a curve connecting two measurements, but by an area on the diagram.

Four other single-value measurements that fall somewhat apart from the main line of argument developed above may be briefly mentioned.

An interesting method of measuring soil fertility developed by Atkins has been studied. The electrical conductivity of a soil suspension is measured and the increase in conductivity after a fixed period (seven days) is taken as an index of the biological activity in the soil, and therefore of its inherent fertility. The method was applied to soil samples taken in the past from the classical plots and stored in the air-dry condition ; the increase in conductivity of the suspensions made from these samples fall in the same order as the corresponding crop-yields in the year of sampling. The method might repay an extended trial as a simple qualitative measurement of soil fertility.

The so-called hygroscopic coefficient, which has been much used in America as a single-value measurement for soils, was subjected to critical examination and found to be unamenable to accurate measurement. The conception of a hygroscopic coefficient is, in fact, fundamentally unsound ; the moisture content at 50 per cent. relative humidity is much to be preferred.

The heat-of-wetting measurement was introduced by Mitscherlich as an index of soil heaviness, but subsequently abandoned in favour of a hygroscopicity determination. Recently, refinements have been introduced in the method, and the results seem, in certain circumstances, to be related to the physical condition of the soil, and to be correlated with other soil properties determined in the field or by laboratory methods. Experiments on pure single-base clays gave the interesting result that the heat-of-wetting represents a specific proportion of the heat-of-hydration of the adsorbed cations in their free state.

Returning to the question of soil heaviness, a new method has been developed[(29)] which gives a satisfactory and rapid laboratory

(29) R. K. Schofield and G. W. Scott Blair—" Rapid Methods of Examining Soils. I. Measurements of Rolling Weights." J. Agric. Sci., 1932, Vol. XXII, pp.135-144 ; R. K. Schofield and G. W. Scott Blair—" The Pachimeter, a Machine for Measuring the Shearing Strength of Plastic Bodies." Trans. Ceramic Soc., 1932, Vol. XXXI, pp. 79-82 ; G. W. Scott Blair and R. K. Schofield—" The Pachimeter as an Instrument for Testing Materials, with Special Reference to Clays, Soils, and Flours." J. Rheology, 1932 , Vol. III, pp. 318-325.

measure of this factor. A plastic cylinder of the soil is rolled backwards and forwards between two plates and the weight on the upper plate is slowly increased until it exerts a certain critical stress which causes the cylinder to lengthen.

Clay aggregates and tilth.—The phenomenon of crumb, or compound particle, formation in soils is well known to all practical men; their cultivation methods are designed to produce this aggregation, to which the term " good tilth " is generally applied. Although good tilth is at once apparent to visual inspection, explanations in scientific erms are almost completely non-existent, and most text-books give only the attractive but strained analogy with the flocculation and deflocculation of weak clay suspensions. The subject has recently been taken up in the Physical Department and, for the first time, a satisfactory explanation of the main factors concerned in the process of tilth formation has been given.[30]

It has been shown that clay particles can form strong aggregates, or crumbs, when dry, only if the clay particles are sufficiently small, if there are a sufficient number of small exchangeable ions on the clay, and if the clay has been dried from a dispersion medium whose molecules are polar and sufficiently small.

An hypothesis in accordance with the experimental results is that cations can orientate polar molecules of the dispersion liquid around them with a power proportional to their surface density of charge; this power is also possessed by the free negative charges on the clay particle, so that when the dispersion liquid has nearly all been removed (i.e. when the soil or clay has dried appreciably) the cations bind the negative charges on two clay particles together by means of bridges of strongly orientated molecules of the polar dispersion liquid.

Soil Cultivation

When an implement is drawn through the soil its resistance is determined by two groups of factors relating to the design and construction of the implement itself and the physical properties of the soil. The group belonging to the implement lie within the province of agricultural engineering and form the subject of study at another Institution; only incidental references will be made to them here. The second group—the soil factors—exert their influence through such properties as soil cohesion, plasticity and friction. They are susceptible to laboratory examination, and instances of their relation to the behaviour of soil during cultivation have been given in the preceding sections. The soil resistance to cultivation is a kind of integrated effect of numerous physical properties; hence, the study of soil resistance has considerable scientific as well as practical interest. The field experiments have taken both these aspects into account: the growth and response of farm crops to different systems of cultivation has been investigated as well as the relations between the cultivation systems and the soil properties.

It was necessary to evolve a dynamometer that would give a continuous trace of soil resistance, together with accessory measurements such as speed and depth of cultivation. For some time, a

(30) E. W. Russell.—" The Interaction of Clay with Water and Organic Liquids as Measured by Specific Volume Changes and its Relation to the Phenomena of Crumb Formation in Soils." Phil. Trans. Roy. Soc. London, A, 1934, Vol. CCXXXIII, pp. 361-389.

modified form of a dynamometer designed for road-traction measurements was used [31]. The instrument gave quite satisfactory service, but the recording system needed skilled attention, and, owing to its weight, the dynamometer was not suitable for tests with the lighter forms of cultivation. A new type was therefore constructed [32], based on the " Stress Recorder " made by the Cambridge Scientific Instrument Company. The new instrument is much lighter than the old one, and the records are impressed in the form of a groove on a narrow ribbon of celluloid by styluses with hard points. The celluloid is not scratched but flows under the pressure of the point ; the groove has excellent optical properties so that a greatly magnified copy can be obtained in the ordinary way. In addition to the trace of soil resistance, a time scale is impressed automatically on the ribbon, and the operator carries a tapping key connected to an electro-magnetic stylus, so that notes in the Morse code can be also impressed on the ribbon. This last feature is of great use, since it obviates the risk of confusion in examining the records of cultivation when a complicated set of plots is being cultivated.

The dynamometer was used in a series of investigations [33], and the main conclusions are summarised below. One very interesting and unexpected result was to demonstrate the heterogeneity of soil. A field that was judged by practical farmers to be quite uniform in its soil properties showed the most surprising changes in soil resistance from point to point. These variations—which are reflections of corresponding variations in the inherent soil properties—are substantially permanent : the magnitude of the soil resistance depends, of course, on the season of cultivation, the kind of implement, its depth of work, etc., but the relative fluctuations of soil resistance from point to point are not affected. Heavy applications of artificial manures, and the long continued differences in crop yields of the classical Rothamsted plots have not produced any appreciable modification of the original and inherent heterogeneity of the soil, with the exception of plots receiving a heavy dressing of dung or of chalk, where, as would be expected, there is a definite lowering of the soil resistance. The inherent variations in soil resistance, disclosed by the dynamometer during soil cultivation with implements, change slowly from point to point. The question whether these changes were themselves average values of larger and more rapid fluctuations within distances of a few inches was examined with another instrument which measures the force needed to drive a vertical rod into the soil : the instrument is, in principle, a miniature pile-driver. Wide variations of resistance

(31) B. A. Keen and W. B. Haines—" Studies in Soil Cultivation. I. The Evolution of a Reliable Dynamometer Technique for Use in Soil Cultivation Experiments." J. Agric. Sci., 1925, Vol. XV, pp. 375-386.

(32) W. B. Haines and B. A. Keen—" Studies in Soil Cultivation. IV. A New Form of Traction Dynamometer." J. Agric. Sci., 1928, Vol. XVIII, pp. 724-733 ; " A New Dynamometer, Suitable for all Types of Horse and Power Drawn Implements." Proc. First Internat. Cong. Soil Sci., 1927, Vol. I, pp. 405-411.

(33) B. A. Keen and W. B. Haines—" Studies in Soil Cultivation. II. A Test of Soil Uniformity by Means of Dynamometer and Plough " ; " Studies in Soil Cultivation. III. Measurements on the Rothamsted Classical Plots by Means of Dynamometer and Plough." J. Agric. Sci., 1925, Vol. XV., pp. 375-406 ; B. A. Keen and G. H. Cashen—" Studies in Soil Cultivation. VI. The Physical Effect of Sheep Folding on the Soil." J. Agric. Sci., 1932, Vol. XXII, pp. 126-134 ; B. A. Keen—" The Use of the Dynamometer in Soil Cultivation Studies and Implement Trials." J. Roy. Agric. Soc. England, 1925, Vol. LXXXVI, pp. 30-43 ; " The Value of the Dynamometer in Cultivation Experments and in Soil Physics Research." Proc. First Internat. Cong. Soil Sci., 1927, Vol. I, pp. 412-428 ; B. A. Keen and E. J. Russell—" The Effect of Chalk on the Cultivation of Heavy Land." J. Min. Agric., 1921, Vol. XXVIII, pp. 419-422.

were found between points whose horizontal distanced apart was only 6 ins. The large and small scale heterogeneity thus demonstrated is one of the reasons for the modern statistical arrangement of field plots which was described at length in last year's Report.

A result of considerable practical importance is that soil resistance increases only slowly with speed of cultivation. The design of cultivation implements is of necessity a compromise between numerous conflicting requirements, but the farmer requires the maximum speed of travel, and it is important to note that the possibility of increased soil resistance at higher speeds can be ignored.

One means of reducing the soil resistance at any given speed has been demonstrated both in the laboratory and in full-scale practical trials.(34) The soil colloids carry a negative charge, hence under the action of an electric current water will move through the soil and be deposited on the negative electrode. If the mouldboard of a plough is insulated from the frame, and made the negative electrode, a film of water will be deposited on it, and the frictional resistance of the furrow slice passing over the mouldboard will be reduced. Measurable reductions of draft were obtained in field trials with an improvised and inefficient arrangement, and the method deserves commercial attention. It is likely to be of considerable use on soils that do not scour easily. The "gumbo" soils of Mexico are a well-known example and instances of English soils in Northamptonshire and Lincolnshire have also been observed. In the latter cases the probable cause is a high percentage of silt in the soil.

The effect of different methods of cultivation has also been studied at Rothamsted.(35) The immediate disintegration of soil by implements has been investigated by passing blocks of soil before and after cultivation through a series of sieves with mesh sizes varying from $1\frac{1}{2}$ ins. square to $\frac{1}{10}$ in., and comparing the percentages of the original sample left on the sieves. The kind of tilth produced by spring ploughing or cultivations is much more controlled by the weather of the previous winter than by the intensity of the spring treatment. In the case of summer cultivations, e.g., hoeing between root crops, there is a strong suggestion that extra cultivations above those necessary to kill weeds, are without benefit to the final yield and may even lead to appreciable reduction, but further experiments in a variety of seasons will be made before a final conclusion is given. Much attention has been given to rotary cultivation. In this method the soil is acted upon by rotating tines and it is claimed that a seed-bed can be produced in one operation, in place of the series that is needed with the traditional range of implements. The main purpose of these experiments is to ascertain if the method is suitable for arable agriculture on medium and heavy soils, which are commonly stated by practical men to require careful and skilled cultivations if a good tilth is to be secured. One of their objections to rotary cultivation is that it gives too fine a tilth. The sieving method described above shows this is not the case; the tilth is no finer than that

(34) E. M. Crowther and W. B. Haines—"An Electrical Method for the Reduction of Draught in Ploughing." J. Agric. Sci., 1924, Vol. XIV, pp. 221-231; "An Electrical Method for the Reduction of Draught in Ploughing." Imp. and Mach. Rev., 1924, Vol. L, pp. 1003-1005.

(35) B. A. Keen and the Staff of the Soil Physics Department—"Studies in Soil Cultivation. V. Rotary Cultivation." J. Agric. Sci., 1930, Vol. XX, pp. 364-389; B. A. Keen—"Experimental Methods for the Study of Soil Cultivation." Emp. J. Exper. Agric., 1933, Vol. I, pp. 97-102.

obtained with the ordinary implements. It is, however, much looser, and the methods for dealing with this new condition and turning it to advantage are still being worked out. In the early stages of growth a rotary cultivation tilth is superior to the normal type : germination and early growth are both better, and although the advantage is usually lost by harvest time, the final yields are usually as good as those given by normal cultivations. This result is obtained in spite of the extra weediness of rotary cultivated plots, which is probably a consequence of the action of the rotating tines. The weed seeds are distributed throughout the depth of cultivation whereas the normal methods encourage germination only in the thin surface layer, where hoeing can easily deal with them.

If these technical difficulties of rotary cultivation can be overcome, the way is clear for an appreciable reduction in the heavy costs of cultivations that the arable farmer must face. The field experiments are therefore being actively continued.

THE CHEMISTRY OF SOILS AND FERTILISERS

E. M. Crowther

The general object of the work of the Chemistry Department under Mr. H. J. Page, from **1920** to **1927**, and since then under the writer, has been the study of the chemical aspects of soil fertility and soil formation. In recent years most of the investigations have dealt with material provided by field experiments at Rothamsted, Woburn and commercial farms on which field experiments are conducted by the Rothamsted staff or local agricultural officers. Several soil investigations have also been carried out on overseas soils, especially from the tropics.

One of the most urgent problems is to devise better methods of obtaining precise agricultural information on soil fertility and crop nutrition. Much of the work of the Department is, therefore, devoted to improving the methods of field experimentation, especially on fertilisers, and to supplementing the crude yields by analyses of the crops. Soils from the experimental centres are analysed by a variety of chemical methods to ascertain how far the results of chemical analyses agree with the agricultural experience expressed in the results of the field trials. The soils of the long-continued experiments at Rothamsted and Woburn are studied to measure the cumulative secondary effects of fertilisers. Systematic samplings and analyses on these classical plots and on those of some of the complex replicated experiments are made for periods of a few years to follow the seasonal cycles in some of the main factors in soil fertility. Much of the laboratory work involves parallel investigations in the pot culture house.

Soil Colloids and Ionic Exchange

It is now generally recognised that the amounts and composition of the soil colloids and the exchangeable ions associated with them are vital factors in determining the physical and chemical properties of soils and the availability of plant nutrients.[1] The first investigations on exchangeable bases were made on the soils of the Broadbalk

(1) H. J. Page—"The Nature of Soil Acidity." Trans. II Comm. Int. Soc. Soil Sci., Vol. A., Gron., 1926, pp. 232-244 ; C. E. Marshall—"Some Recent Researches on Soil Colloids. A Review." Journ. Agri. Sci., 1927, Vol. XVII, pp. 315-332.

continuous wheat plots and on some coastal soils which had been flooded by sea water.(2) The study of the soil colloids began with a series of investigations between 1921 and 1927, on the nature and origin of the humic material.(3) This was shown to be derived from the lignin constituents of plants by condensation with protein. Soils in which widely different carbon contents had been produced by cultural and manurial treatments had humic materials with closely similar compositions and properties.

Work on the composition of the inorganic soil colloids or clay fraction began with an examination of earlier American data.(4) It was shown that the ratio of silica to alumina in the clay fraction fell as the rainfall increased and rose as temperature increased; the relative rates were such that for similar parent materials constant silica : alumina ratios are found when an increase in mean annual temperature of 1°C. is accompanied by an increase of 4 cm. in mean annual rainfall. For constant climatic conditions the silica : alumina ratio was greater on soils from parent materials which had been subjected to repeated reworking in water. A similar method of statistical analysis was also applied to problems of soil distribution in continental areas. More recently the chemical analysis of clays has been simplified by a method for the direct determination of aluminium.(5) Investigations of soils from Burma, Malay, Nyasaland and other countries have given ample additional evidence for the rule that hot wet regions tend to have clays rich in iron and aluminium, while those in arid regions are rich in silica. It has been found however, that although soils of the same type have similar clays, the ratio of silica to alumina or sesquioxides is not in itself a sufficient index of the composition and properties of the soil. Thus, a pair of contrasted but adjacent soils in a cotton experiment station in Nyasaland (an acid red loam and a neutral grey-brown soil with carbonate accumulations in the lower horizons) had clays with closely similar silica-sesquioxide ratios. Further fractionation and characterisation of clay fractions are required, and we are using a series of physicochemical, mineralogical and X-ray methods for these purposes.

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(2) H. J. Page and W. Williams—"Studies on Base Exchange in Rothamsted Soils." Trans. Faraday Soc., 1925, Vol. XX, pp. 573-585; H. J. Page and W. Williams—"The Effect of Flooding with Sea Water on the Fertility of the Soil." Journ. Agri. Sci., 1926, Vol. XVI, pp. 551-573.

(3) H. J. Page—"The Part Played by Organic Matter in the Soil System." Trans. Faraday Soc., 1922, Vol. XVII, pp. 272-287; E. M. Crowther—"Further Experiments on the Effect of Removing the Soluble Humus from a Soil on its Productiveness." Journ. Agri. Sci., 1925, Vol. XV, pp. 303-306; H. J. Page and C. E. Marshall.—"The Origin of Humic Matter." Nature, 1927, Vol. CXIX, p. 393; "Studies on the Carbon and Nitrogen Cycles in the Soil." I. H. J. Page—"Introductory." Journ. Agri. Sci., 1930, Vol. XX, pp. 455-459; II. C. W. D. Arnold and H. J. Page—"The Extraction of the Organic Matter of the Soil with Alkali." Journ. Agri. Sci., 1930, Vol. XX, pp. 460-477; III. M.S. du Toit and H. J. Page—"The Formation of Natural Humic Matter." Journ. Agri. Sci., 1930, Vol. XX, pp. 478-488; IV. M. M. S. du Toit and H. J. Page—"Natural and Artificial Humic Acids." Journ. Agri. Sci., 1932, Vol. XXII, pp. 115-125; V. H. J. Page—"The Origin of the Humic Matter of the Soil." Journ. Agri. Sci., 1932, Vol. XXII, pp. 291-296; VI. R. H. Hobson and H. J. Page—"The Extraction of the Organic Nitrogen of the Soil with Alkali." Journ. Agri. Sci., 1932 Vol. XXII pp. 297-299; VII. R. P. Hobson and H. J. Page—"The Nature of the Organic Nitrogen Compounds of the Soil; 'Humic' Nitrogen." Journ. Agri. Sci. 1932 Vol. XXII, pp. 497-515; VIII. R. P. Hobson and H. J. Page—"The Nature of the Organic Nitrogen Compounds of the Soil; 'Non-Humic' Nitrogen." Journ. Agri. Sci., 1932, Vol. XXII, pp. 516-526. H. L. Richardson—"The Use of Hydrogen Peroxide for Estimating Humification." Soil Sci., 1931, Vol. XXXII, pp. 167-171.

(4) E. M. Crowther—"The Relationship of Climatic and Geological Factors to the Composition of Soil Clay, and the Distribution of Soil Types." Proc. Roy. Soc. (B), 1930, Vol. CVII, pp. 1-30; E. M. Crowther—"Soils and Climate." Min. Agric., Rept. Agri. Meteorol. Conf., 1931, pp. 5-11; E. M. Crowther—"Climate, Clay Composition and Soil Type." Proc. 2nd. Intern. Cong. (1930) Soil Sci., Comm. V, 1932, pp. 15-23.

(5) S. P. Aiyer—Ph.D. Thesis, University of London, 1934.

https://doi.org/10.23637/ERADOC-1-66

A serious error was detected in the standard quinhydrone method for measuring soil reaction, and traced to the effects of readily reducible oxides of manganese.(6) This was followed up by a study of the amount and rate of solution of the exchangeable and readily reducible manganese in soils on which oats in this country and tea in Ceylon showed symptoms of deficiency diseases. The work suggested that soils with relatively large amounts of manganese oxides may yet contain very little readily soluble manganese.

Methods for the determination of the exchangeable bases and acidity (unsaturation) are being developed in suitable forms for combination with routine analyses for readily soluble plant nutrients.

Changes in the Soils of Long Continued Field Trials

The plots of Stackyard Field at Woburn were sampled fully in 1927 on the completion of fifty years of continuous experimentation with fertilisers and crop rotations. The sampling was repeated in 1932, and samples were available for a number of other years, including a few of the earlier ones. Soil samples from these plots were analysed for (1) carbon, (2) nitrogen, (3) exchangeable bases, (4) soil reaction, (5) composition of clay fractions, to study the changes on this light and poorly buffered soil under a wide variety of treatments.(7)

Under continuous wheat and barley without farmyard manure, one-third of the soil organic matter was lost in fifty years ; farmyard manure at the rate of about 7 tons per acre per annum merely sufficed to maintain the original organic matter content. Superphosphate had no appreciable effect on the soil reaction or base status, even after fifty annual applications. From plots which had been rendered almost infertile by sulphate of ammonia and then subdivided for varying dressings of lime, it was possible to show that the rate of loss of lime fell off rapidly as the soil became progressively more acid. An attempt was made to assess the effects of nitrate of soda and sulphate of ammonia on the lime status of the soil, and it was concluded that, if lime were to be added periodically to keep the composition of the soil and the crops with sulphate of ammonia similar to those with nitrate of soda, the amount of lime needed would be equivalent to both the nitric and the sulphuric acids produced by the oxidation of the sulphate of ammonia. The comparison is complicated, however, by the circumstance, which is well illustrated in recent pot experiments at Woburn, that nitrate of soda has a much more potent effect on plants grown in very acid soil than can be accounted for by the mere reduction of loss of calcium by leaching. These Woburn data and similar ones on the reaction, nitrogen and phosphoric acid contents of Rothamsted

(6) S. G. Heintze and E. M. Crowther—"An Error in Soil Reaction Determination by the Quinhydrone Method." Trans. Sec. Comm. Inter. Soc. Soil Sci., Budapest, 1929. Pt. A., pp. 102-111; E. M. Crowther and S. G. Heintze—In "Report of the Soil Reaction Committee of the International Society of Soil Science. I. Results of Comparative Investigations on the Quinhydrone Method II. Conclusions and Recommendations." Soil Res. 1930. Vol. II, pp. 28-139, 141-152; S. G. Heintze—"The Use of the Glass Electrode in Soil Reaction and Oxidation-Reduction Potential Measurements." Journ. Agri. Sci., 1934, Vol. XXIV, pp. 28-41.

(7) E. M. Crowther and J. K. Basu—"Studies on Soil Reaction VIII. The Influence of Fertilisers and Lime on the Replaceable Bases of a Light Acid Soil after Fifty Years of Continuous Cropping with Barley and Wheat." Journ. Agric. Sci., 1931. Vol. XXI, pp. 689-715; E. M. Crowther—"The Loss of Lime from Light Soils (an Examination of the Woburn Barley and Wheat Soils)." Journ. Roy. Agri. Soc. Eng., 1932, Vol. XCIII, pp. 199-214; A. Walkley. Ph.D. Thesis, University of London, 1933.

classical fields show wide irregularities between comparable plots, and emphasise the danger of basing conclusions on differences between unreplicated plots. The main differences in the carbon contents of the Woburn plots proved to be due to coal fragments and not to normal soil organic matter.

"Available" Nutrients; Phosphate and Potash

In spite of a vast output from many countries of papers on methods for the estimation of fertiliser requirements by chemical analysis of soils, comparatively little real progress has yet been made, mainly because it has rarely been possible to conduct a sufficient number of precise field experiments to standardise the methods[8]. The factors involved are necessarily so complex that the most that can be expected is to establish analytical limits for given types of farming and soil conditions. Proposed methods must constantly be subjected to critical trials and, up to the present, the problem of organising the necessary trials has not been seriously attacked. At Rothamsted, our main contribution to the subject has been an attempt to develop and, at the same time, to simplify the technique of field experimentation. Our current scheme of a 27 plot test embodying all combinations of zero, single and double dressings of nitrogenous, phosphatic and potassic fertilisers promises to meet the general requirements. It provides a general survey of the nutrient requirements of a given crop and soil; it shows how the response varies with the rate of dressing, tests the magnitude of interactions between fertilisers, and provides valid estimates of the errors of all of the points tested. The crop responses required to establish statistical significance are of about the same order as those which would be profitable to the grower. We have used this technique for a number of potato experiments, especially in fenland soils, and for sugar beet experiments in 1934 and 1935. We have also arranged a series of such experiments on over 1,000 acres of commercial rubber trees in Malaya. The results so far available in this country have not merely provided useful material for soil investigations, but, in addition, have brought out some unexpected results of practical importance. Thus on some black fenland soils, commonly believed only to require superphosphate, we have had large responses to both nitrogen and potash. On the other hand, in a series of experiments on sugar beet on farms normally receiving relatively heavy dressings of fertilisers, we have obtained very few responses to phosphate or potash. In selecting sites for such experiments, it has been our common experience that soils, chosen by farmers and beet factory agriculturists as poor, very frequently prove to be acid and not necessarily deficient in nutrients by chemical tests. The few experiments already conducted suggest that there is room for considerable improvements in fertiliser practice, by economy on some soils, and by more liberal manuring on others.

The sugar beet series of experiments has so far failed to provide good correlations between field responses and analytical data, because there were very few responses in the field. During the last two dry summers, the success of sugar beet, wheat and other deeply

(8) E. M. Crowther—"The Present Position of the Use of Fertilisers." Journn. Roy. Soc. Eng. 1931, Vol. XCII, pp. 16-18.

rooting crops emphasised the importance of the deep subsoil, and suggested that these crops obtain nutrients as well as water from the deeper soil horizons. Unfortunately, comparatively little is known about the effective root range of our cultivated crops. During the summer drought of 1934, we sampled the soils of our sugar beet experiments to four feet, and were able to divide them into groups with and without subsoil water supplies, by comparing the field moisture contents with those obtained when all soils were brought artificially to comparable degrees of moistness in the laboratory. The beets grown on moist subsoils gave much higher weights of tops per unit of roots and less pure juices ; they also appeared to show more response to superphosphate than those grown on drier subsoils. At Woburn, during 1934, the rate and depth of penetration of beet roots were followed by automatic soil moisture manometers. The roots descended from about 12 inches to 42 inches during July. Towards the end of the season, Dr. Mann excavated and washed out beet roots to a depth of five feet in the soil.

Soil Organic Matter and Crop Rotation

The decomposition of crop residues, organic manures and soil organic matter has been followed in several series of field experiments with the object of trying to relate the availability of soil nitrogen to the nature of the readily oxidisable organic matter, and to the general soil conditions during the interval between the formation and the utilisation of the inorganic nitrogen.(9) The first problem was the paradox of the Woburn green manure plots on which wheat grown repeatedly after summer green manures deteriorated rapidly, especially after tares.(10) It was shown that the conditions in this light soil favoured rapid decomposition of the crop residues and loss of nitrate by leaching before it could be utilised by the wheat plants in the following spring. Subsequent work by Dr. Mann showed that there are other, as yet unexplained, losses of nitrogen whenever green manures are added to the soil long before the crop can utilise the nitrate produced. Efficient green manuring requires the careful timing of operations so that the absorption of available nitrogen occurs soon after the incorporation of green manure material.

In a ley and fallow experiment at Rothamsted, the changes in readily oxidisable organic matter were followed by measuring the end products of oxidation—CO_2, NH_3, NO_3—on incubating soil samples under optimal conditions in the laboratory.(11) Fallow caused rapid losses of oxidisable carbon, and clover ley increased nitrifiable nitrogen. Nitrates accumulated in the field during fallow in summer and autumn, but were lost from the surface soil during winter. In spite of this, the following wheat crops showed wide yield differences (wheat after fallow being twice that after ryegrass). These differences were correlated with the nitrate contents of the

(9) E. M. Crowther—" Soil Organic Matter and Crop Rotation." Second Conference on Cotton Growing Problems, Empire Cotton Growing Corporation, 1934, pp. 319-329.

(10) T. J. Mirchandani—" The Effect of Summer Green Manures on the Ammonia and Nitrate Contents of Soil Cropped for Winter Wheat." Journ. Agri. Sci., 1931, Vol. XXI, pp. 458-468 ; E. M. Crowther and T. J. Mirchandani—" Winter Leaching and the Manurial Value of Green Manures and Crop Residues for Winter Wheat." Journ. Agri. Sci., 1931, Vol. XXI, pp. 493-525. E. M. Crowther and H. H. Mann—" Green Manuring and Sheep Folding on Light Land "—An Account of the Green Manuring Experiments at the Woburn Experimental Station, 1893-1933. Journ. Roy. Agri. Soc. Eng., 1933, Vol. XCIV, pp. 128-151.

(11) E. R. Orchard—Ph.D. Thesis, University of London, 1933.

soil in the previous summer. It seems necessary to conclude that in the heavy Rothamsted soil the nitrate washed out of the surface in the autumn and early winter is stored in the structural units of the subsoil. Heavy rains drain away through the main cracks and channels, but the nitrate is lost much more slowly, and presumably much of it remains available to deeply rooting crops in the following spring. It seems possible that this hypothesis of the storage of nitrate, and possibly of other nutrients, in subsoils with well developed structures may serve to bridge the gulf between the pedologist's concern with the deeper horizons and the analyst's use of surface samples. It is almost impossible to determine by direct experiment the depth from which plants absorb nutrients, but it may be possible to interpret the effects of changes in surface nutrients in terms of the extent of subsoil storage.

Experiments on a synthetic humic acid prepared from coal by a patented process showed that the organic nitrogen present had little nutritive value for crops.([12]) Parallel experiments, conducted on four soils in pot cultures on barley and also in incubators in the laboratory, gave closely concordant results, suggesting that the technique now employed to compare the rates of decomposition of organic manures is satisfactory.

Up to the present, we have found only inappreciable differences between the rates of nitrification of the slow-acting organic manures favoured by market gardeners, and it seems probable that their essential merit lies in their physical state. Lumps and granules allow only slow attack, diffusion, and leaching, and they may, therefore, maintain moderate nitrate concentrations throughout surface and subsoil with less loss by leaching than occurs from readily soluble and diffusible salts.

Short period experiments on repeatedly mown grass and systematic analyses on the Park Grass plots for three years showed that more nitrogen is present as ammonia than as nitrate in normal grassland soils.([13]) Evidence was obtained to confirm an old—and sometimes forgotten—view that grasses assimilate ammonia directly and without prior nitrification. The rate of nitrification depends in part on the soil reaction, but some Park Grass soils which have received neither sulphate of ammonia nor lime have very feeble nitrifying powers. Low nitrification means that the available nitrogen and, presumably, the grass roots, tend to concentrate near the surface.

The decomposition of organic matter under the extreme conditions of waterlogging, as in rice soils, was investigated.([14]) A deaminase was extracted which was capable of splitting off ammonia in waterlogged soils in the absence of living organisms.

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(12) E. M. Crowther and W. E. Brenchley—"The Fertilising Value and Nitrifiability of Humic Materials Prepared from Coal." Journ. Agri. Sci., 1934, Vol. XXIV, pp. 156-176; E. M. Crowther—"A Note on the Availability of Organic Nitrogen Compounds in Pot Experiments." Journ. Agri. Sci., 1925, Vol. XV, pp. 300-302.

(13) H. L. Richardson—"The Behaviour of Nitrogenous Fertilisers in Grassland Soils." Agric. Prog., 1933, Vol. X, p. 160-163.

(14) "Biochemistry of Water-logged Soils." I. V. Subrahmanyan—"The Effect of Waterogging on the Different forms of Nitrogen, on the Reaction, on the Gaseous Relationships, and on the Bacterial Flora." Journ. Agri. Sci., 1927, Vol. XVII, Pt. IV, pp. 429-448; II. V. Subrahmanyan—"The Presence of a Deaminase in Water-logged Soils and its Role in the Production of Ammonia." Journ. Agri. Sci., 1927, Vol. XVII, Pt. IV, pp. 449-467; III. V. Subrahmanyan—"Decomposition of Carbohydrates with Special Reference to Formation of Organic Acids." Journ. Agri. Sci., 1929. Vol. XIX, Pt. IV, pp. 627-648.

The Availability of Fertilisers

Studies on the behaviour of fertilisers may have immediate practical value and, in addition, may reveal important factors in soil fertility. Among the nitrogenous fertilisers we have made detailed studies on the decomposition of calcium cyanamide, which undergoes a complex series of changes before its nitrogen becomes available to plants.[15] It is commonly said to act more slowly than sulphate of ammonia, but the delay, especially in nitrification, occurs after the cyanamide nitrogen has been converted into ammonia. This is not necessarily a disadvantage, for ammonia is less liable to loss by leaching, and, in addition, may be more rapidly available than nitrate. In some pot culture experiments with barley on a rich acid soil we invariably got better results from cyanamide, which stopped nitrification, than from sulphate of ammonia. The barley plants with cyanamide tillered more rapidly, and appeared to utilise ammonia nitrogen more rapidly than nitrate nitrogen. In field practice the differences between nitrates and ammonia are often masked by the more rapid diffusion of the nitrate through the soil. We have obtained some evidence that cyanamide or dicyanodiamide may be preferable to sulphate of ammonia for autumn dressings of winter wheat on heavy soil.

Basic slags have received detailed study in the Chemistry Department, partly because the English slag problem is unique in the low solubility of some of the materials, and partly because the proper evaluation of slags called for an improved experimental technique, especially on grassland.[16] Basic slags of less than 35 per cent. solubility by the conventional Wagner citric acid test were shown to be definitely less effective as sources of available phosphorus than those of more than 75 per cent. citric solubility. In a series of six hay trials and three repeated mowing trials at centres throughout England for four years, we measured the total yields of dry matter, protein and phosphoric acid in the herbage from four phosphatic fertilisers. All of the experiments gave consistent results for the recovery of the added phosphoric acid. High-soluble slags and superphosphate gave similar recoveries: low-soluble slags provided only about one-third as much phosphoric acid to the crops: on acid soils mineral phosphate was as good as high-soluble slag, and on neutral soils as bad as low soluble slag. In a limited number of trials, it is difficult to distinguish soil from climatic conditions.

(15) "Studies on Calcium Cyanamide." I. E. M. Crowther and H. L. Richardson—"The Decomposition of Calcium Cyanamide in the Soil and its Effects on Germination, Nitrification and Soil Reaction." Journ. Agri. Sci., 1932, Vol. XXII, pp. 300-324; II. B. K. Mukerji—"Microbiological Aspects of Nitrification in Soils under Varied Environmental Conditions." Journ. Agri. Sci., 1932, Vol. XXII. pp. 335-347; III. H. L. Richardson, "Storage and Mixing with Superphosphate" Journ. Agri. Sci., 1932 Vol. XXI, pp. 348-357; IV. H. L. Richardson—"The Use of Calcium Cyanamide and Other Forms of Nitrogen on Grassland." J. Agri. Sci., 1934, Vol. XXIV. pp. 491-510; H. L. Richardson and E. M. Crowther—"The Utilisation of Calcium Cyanamide in Pot Culture Experiments." Journ. Agri. Sci., 1935, Vol. XXV, pp. 132-150; H. L. Richardson—"Field Experiments on the Action of Calcium Cyanamide on Germinating Seeds and on Charlock in Barley." Emp. Journ. Expt. Agri., Vol. III, No. 9, pp. 41-49, 1935. E. M. Crowther—"Comparative Field trials of Calcium Cyanamide and Other Nitrogenous Fertilisers on Arable Crops". Emp. Journ. Expt. Agri., 1935, Vol, III, pp, 129-143.

(16) R. G. Warren, C. T. Gimingham and H. J. Page—"The Chemistry of Basic Slag I. The Determination of Fluorine in Basic Slag." Journ. Agri. Sci., 1925, Vol. XV, pp. 516-528; A. W.. Greenhill—"The Availability of Phosphatic Fertilisers as shown by an Examination of the Soil Solution and Plant Growth." Journ. Agri. Sci., 1930, Vol. XX, pp. 559-572; E. M. Crowther and R. G. Warren—"The Fertiliser Value of Basic Slags and Other Phosphates." Agric. Prog. 1934' Vol. XI, pp. 99-105; E. M. Crowther—"Basic Slags and Mineral Phosphates." Journ. Roy. Agri. Soc. Eng., 1934, Vol. XCV., pp. 34-53; E. M. Crowther and R. G. Warren—Appendices to Interim Reports of Permanent Committee on Basic Slag, Ministry of Agriculture, annually since 1927.

There is evidence from practical experience and also from some of our recent pot experiments that mineral phosphate may give much better results in moist soils than in drier ones. Swede trials in Scotland in 1934 showed that low-soluble slags, though inferior to the more soluble ones, were capable of greatly increasing the yields. Pot experiments on perennial rye-grass grown in sand-calcium bentonite mixtures at constant moisture contents showed extraordinarily close agreement between the yields or the uptake of phosphoric acid, and the citric acid solubilities of a dozen basic slags.

Our experience of field and pot experiments on phosphatic fertilisers suggests that much of the conflict and confusion in the results of the older field experiments was due to the inevitable uncertainties from unreplicated experiments, reliance on yields alone and failure to group the experimental soils. In recent years, each new series of field or pot experiments has confirmed or extended the conclusions from earlier ones.

The Composition of Crops

From the beginning of the Rothamsted experiments ninety years ago, it has been the rule to prepare and store samples of the produce from most of the experimental plots. Such samples are examined to determine the effect of soil, season and treatment on the composition of the crops. In many comparative experiments on fertilisers the total contents or percentage recoveries of a given nutrient give better measurements of availability than the yields alone. For many crops it is necessary to consider how far changes in composition affect the quality of the product as a food, feeding stuff or industrial raw material. Sometimes, as in sugar beet, the methods of analysis and valuation are either relatively simple or based on well recognised conventions. For other crops it has been necessary to carry out experiments or ambitious programmes of research in conjunction with the industry concerned.([17]) Thus, in our work on the effect of soils and fertilisers on the composition of potatoes we had the collaboration of the research staff of Messrs. Lyons. For over ten years members of the staff of the Institute of Brewing Research Scheme worked in the Chemistry Department on the composition of barley. It was shown([18]) that soil and season were the most important factors governing quality of barley for malting and brewing ; variety and fertilisers had much less effect. The most important soil factor appeared to be the presence or absence of nitrogenous organic matter. Nitrification late in the life of the barley plant tended to give grain with high nitrogen and low malting quality.

(17) E. M. Crowther—" Influence of Fertilisers on the Yield and Composition of Potatoes." Brit. Assoc., Rept. of Bristol Meeting, 1930, p. 420 ; E. M. Crowther—" Results of Recent Fertiliser Experiments." Problems of Potato Growing, Rothamsted Conferences, 1934, Vol. XVI, pp. 34-40.

(18) E. J. Russell and L. R. Bishop—" Investigations on Barley. Report on the Ten Years of Experiments under the Institute of Brewing Research Scheme. 1922-1931." Journ. Inst. Brew 1933, Vol. XXXIX, pp. 287-421 ; L. R. Bishop—" The Nitrogen Content and ' Quality ' of Barley.." Journ. Inst. Brew., 1930, Vol. XXXVI, pp. 352-364.

General

Much time has necessarily been devoted to the improvement and standardisation of analytical methods.[19]

The Department has taken an active part in the cooperative investigations on soil analysis by Committees of the Agricultural Education Association[20], and of the International Society of Soil Science (Mechanical Analysis and Soil Reaction Committees for the Second Congress in Leningrad in 1930, and Organic Carbon and Soil Reaction Committees for the Third Congress in Oxford in 1935.)

Since 1921 the Head of the Chemistry Department has prepared an annual report on the progress of investigations on soils and fertilisers for the Society of Chemical Industry's "Reports on the Progress of Applied Chemistry."

REVIEW OF WORK OF THE BACTERIOLOGY DEPARTMENT

H. G. Thornton

The work that has been carried out in this department can be divided into three sections :—

The quantitative study of the bacterial population of the soil; investigation of various specific bacterial activities that occur in soil; investigations concerning the nodule organism and its relation to leguminous crop plants.

The Quantitative Study of the Bacterial Flora

The study of ecology of the soil micro-population at Rothamsted was initiated by the work of Russell and Hutchinson on partially sterilised soil, which led to the conclusion that an antagonism existed between certain groups of the population, particularly between soil bacteria and protozoa. Some results obtained by Russell and Appleyard at the same time indicated that the numbers of bacteria in soil were far from constant. It was therefore decided further to investigate these fluctuations in numbers, particularly to discover whether they were related in any way with the numbers of soil protozoa. Before this could be done, however, it was necessary to improve the existing technique of plate counting, which was clearly

(19) T. Eden—"A Note on the Colorimetric Estimation of Humic Matter in Mineral Soils." Journ. Agri. Sci., 1924, Vol. XIV, pp. 469-472 ; H. J. Page—"On the Perchlorate Method for the Estimation of Potassium in Soils, Fertilisers, etc." Journ. Agri. Sci., 1924, Vol. XIV, pp. 133-138 ; E. M. Crowther and W. S. Martin—"The Volumetric Determination of Total Carbonic Acid in Dilute Solutions of Calcium Bicarbonate." Journ. Chem. Soc., 1924, Vol. CXXV, pp. 1937-1939 ; E. M. Crowther—"The Determination of Hydrogen Ion Concentration." The Chemists' Year Book, 1928, pp. 610-629 ; E. M. Crowther and J. K. Basu—"Note on a Simple Two-compartment Electrodialysis Cell for the Determination of Exchangeable Bases." Trans. 2nd. Comm. Inter. Soc. Soil Sci., Budapest, 1929, Pt. A., pp. 100-102 ; V. Subrahmanyan—"Determination of Soluble Carbohydrates, Lactic Acid and Volatile Fatty Acids in Soils and Biological Media." Journ. Agri. Sci., 1929, Vol. XIX, Pt. IV, pp. 649-655 ; V. Subrahmanyan—"An Improved Method for the Determination of Dissolved Oxygen in Water." Journ. Agri. Sci., 1927, Vol. XVII, Pt. IV, pp. 468-476 ; R. G. Warren and A. J. Pugh—"The Colorimetric Determination of Phosphoric Acid in Hydrochloric Acid and Citric Acid Extracts of Soils." Journ. Agri. Sci., 1930, Vol. XX, pp. 532-540 ; J. K. Basu—"Studies on Soil Reaction VII. An Electrodialysis Apparatus for the Determination of Replaceable Bases in Soils." Journ. Agri. Sci., 1931, Vol. XXI, pp. 484-492 ; E. Troell—"The Use of Sodium Hypobromite for the Oxidation of Organic Matter in the Mechanical Analysis of Soils." Journ. Agri. Sci., 1931, Vol. XXI, pp. 476-483 ; E. M. Crowther and K. Troell—"Oxidation of Organic Matter in the Pretreatment of Soils for Mechanical Analysis." Proc. 2nd. (1930) Intern. Congr. Soil Sci., Comm. I, 1932, pp. 48-51, pp. 253-255. A. Walkley and I. Armstrong Black—"An Examination of the Degtjareff Method for Determining Soil Organic Matter, and a Proposed Modification of the Chromic Acid Titration Method." Soil Sci., 1934, Vol. XXXVII, pp. 29-38.

(20) E. M. Crowther (with R. Stewart)—"Report of the Analysis of Soils Sub-Committee of the Agricultural Education Association." Agric. Prog., 1934, Vol. XI, pp.1 06-114.

https://doi.org/10.23637/ERADOC-1-66

subject to large errors, for the estimation of which no adequate statistical method existed.

1. *Improvement and Testing of the Plate Technique.*

The earlier plate counts of soil bacteria had been made either upon the gelatine medium which gave inaccurate results owing to liquefaction, or else on agar media containing a high proportion of organic matter. On such agar media great difficulty was experienced owing to the development of spreading colonies on the plates. The investigation of such spreading colonies showed that the spreading was due to active motility of certain bacteria over the surface of the agar plate and that it could largely be checked by employing a synthetic medium of such a composition that growth of these organisms was delayed during the early stages of incubation.(1)

A satisfactory synthetic medium having been developed, a series of tests were made with it to determine the degree of accuracy obtainable and to find out at which stages in the plating technique errors occurred.

It was always recognised that the plate method can give results of only comparative value and that counts on a single plating medium cannot give any idea of the total content of bacteria, since these belong to diverse physiological groups. For such comparative purposes it was shown that, with a carefully standardised technique, the errors due to shaking, diluting the soil and pouring the plates were negligible when compared with those shown between parallel plates of the final dilutions. Such errors are due to two causes: (a) the random distribution of bacteria in the suspension, equal volumes of which are added to each plate, and (b) irregularity in development of colonies in the plate. It was found that in the great majority of counts the whole detectable error was due to random distribution but that in a few cases the irregular development of colonies increased the error. Fortunately it was found possible to detect such departures from random sampling by testing the variance between parallel plates. A simple statistical test was developed for this purpose by the Statistical Department working in collaboration with this department.(2) Thus when parallel plates agree satisfactorily, the error depends directly on the number of colonies counted and any greater variance, causing the results to be questionable, is readily detected by a simple test. The plating technique was thus placed on a sound statistical basis before further quantitative work was attempted.

2. *Short-period Fluctuations in Bacterial Numbers as found by plating.*

The problem was then taken up by workers in the Microbiology Department whose work is elsewhere described. Using the plate method, they found that bacterial numbers in a field soil showed striking fluctuations from day to day. Fluctuations in protozoal numbers were also found: those of active amoebae showing an inverse relationship to the bacteria in about 80 per cent. of cases.

The problem was then taken up in the Bacteriology Department

(1) H. G. Thornton—"On the Development of a Standardised Agar Medium for Counting Soil Bacteria, with especial regard to the Repression of Spreading Colonies." Annals Appl. Biol. **9**, 1922, 241.

(2) R. A. Fisher, H. G. Thornton, and W. A. Mackenzie—"The Accuracy of the Plating Method of Estimating the Density of Bacterial Suspensions." Annals Appl. Biol., **9**, 1922, 325.

where it was shown that large fluctuations in bacterial numbers occurred between samples taken at two-hourly intervals during the day and night. These fluctuations usually bore no relation to either moisture or temperature of the soil.(3)

3. *Development of Microscope Count Method for Counting Bacterial Cells in Soil.*

The work described above was carried out by means of the plate method, but it was recognised that this method enabled only a small fraction of the bacterial flora to be measured and did not enable one to determine whether fluctuations affected the whole bacterial flora or were confined to a fraction comprising organisms adapted to grow on the medium used for plating. The only means of measuring the total bacterial flora is that of direct microscopic examination of soil films. A suitable staining technique for enabling bacteria to be distinguished in such films was developed by H. J. Conn in America and further improved by S. Winogradsky in France and by the Bacteriology Department at Rothamsted. Two very serious difficulties had, however, prevented this staining technique from being developed into an exact quantitative method. These were (a) the difficulty of estimating with any accuracy the minute mass of soil examined in a thin film with an oil immersion objective and (b) the fact that the bacteria were not distributed at random over that film from which microscope fields had to be taken as samples.

These difficulties were eventually overcome by means of a ratio method, the principle of which is as follows.(4) A suspension of indigo particles averaging one micron in diameter is made up, and the number of particles per cubic millilitre is determined by means of a haemocytometer count. A known mass of soil is shaken up in a known volume of this counted suspension. Films of the resulting mixture are prepared and stained. The bacteria and indigo particles are counted in a suitable number of random microscope fields and the ratio of bacteria to indigo is determined. Since the absolute number of indigo particles added per gram of soil is known, the numbers of bacterial cells is calculable from the ratio. The calculation is, of course, independent of the quantity of soil in the film and since the indigo and bacteria are similarly disturbed by the surface tension forces during drying, it is found that the ratios of bacteria to indigo show a random distribution over the film.

The method was subjected to the following tests. (a) Bacterial numbers found in four portions of a single soil sample agreed with a standard error of 3.3 per cent. (b) The results of different workers counting and preparing the films agreed as random samples. (c) Counted suspensions of pure cultures of bacteria added to sterilised soil were estimated with a standard error of 3.5 per cent.

The numbers of bacteria found in soil by this method are of the order of one hundredfold those found by plate counts, and range from 1,000 to 4,000 million per gram. An exploration of some of the plots on Hoos field indicated a connection between the numbers found by the microscope method and the yield of the plots.(4)

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(3) H. G. Thornton and P. H. H. Gray—" The Fluctuations of Bacterial Numbers and Nitrate Content of Field Soils." Proc. Roy. Soc. London, Ser. B, **106**, 1930, 399.

(4) H. G. Thornton and P. H. H. Gray—" The Numbers of Bacterial Cells in Field Soils, as estimated by the Ratio Method." Appendix by R. A. Fisher. Proc. Roy. Soc. London, Ser B , **115**, 1934, 522.

4. *Fluctuations in the Numbers of Bacterial Cells in Soil.*

The above-described method was then applied to the study of the fluctuations in bacterial numbers in soil. It has been found that the total numbers of bacterial cells showed marked fluctuations between samples taken at daily and also at two-hourly intervals (4,5). These fluctuations did not as a rule agree with those found by plate counts from the same samples.

There was usually no correlation between the fluctuations and either temperature or moisture. Significant fluctuations have been found in soil stored in an incubator at constant temperature and moisture. Soil sterilised and supplied with a mixed culture of soil bacteria also showed significant fluctuations in bacterial numbers. This proves that protozoa are not the only cause of fluctuations although in a single experiment in which two-hourly counts of amoebae and bacteria were made, an inverse relationship between them was found.

It seems likely that a somewhat delicate equilibrium exists in the soil both between different groups of bacteria and between bacteria and other forms, and that if a disturbing factor upsets this equilibrium, a series of fluctuations is set up.(5)

Investigations Concerning Special Groups of Bacteria

1. *Cellulose-Decomposing Organisms.*

The study of cellulose-decomposing bacteria began with Hutchinson and Clayton's discovery of the remarkable *Spirochaeta cytophaga*. Since then a considerable number of aerobic cellulose-decomposing bacteria have been isolated and described by workers in the Department. They include one of the few known agar-liquefying bacteria, *Microspira agar-liquefaciens* (6) and some interesting bacteria producing reducing sugars from cellulose (7). An investigation was made to discover what types of organisms were active in decomposing cellulose in natural soil and it was concluded that the nature of the cellulose decomposing flora was determined by the soil's reaction. In acid soils the cellulose was attacked by fungi, in very slightly acid soils principally by *Spirochaeta cytophaga* and in neutral and alkaline soil by a variety of non-sporing bacteria.(8)

Related to this study was an investigation of the bacteriology of farmyard manure decomposition in soil. This showed that the early stages of decomposition are accompanied by a rise in bacterial numbers and by a delay in the production of nitrate or even by an assimilation of soil nitrate. This period probably represents the decomposition of carbon compounds by bacteria which are assimilating nitrogen compounds. There is then a fall in bacterial numbers and a large increase in nitrate which is probably derived from the decom-

(5) C. B. Taylor—Unpublished Thesis. Univ. London, 1935.

(6) P. H. H. Gray and C. H. Chalmers—" On the Stimulating Action of Certain Organic Compounds on Cellulose Decomposition by means of a New Aerobic Micro-organism that attacks both Cellulose and Agar." Ann. Appl. Biol., **11**, 1924, 324.

(7) A. Kalninš—" Aerobic Soil Bacteria that decompose Cellulose." Acta Univ. Latviensis, Lauksaim. Fakult., Ser. I. **11**, 1931, 221.

(8) H. L. Jensen—" The Microbiology of Farmyard Manure Decomposition in Soil. II. Decomposition of Cellulose." Journ. Agric. Sci., **21**, 1931, 81.

https://doi.org/10.23637/ERADOC-1-66

position of bacterial cells.(9) It was found that bacterial protoplasm is, in fact, readily nitrifiable in soil. (10)

2. *Bacterial Decomposition of Aromatic Antiseptics.*

This work arose from a difficulty experienced by growers of glass-house crops who used such compounds as cresylic acid and naphthalene to destroy soil pests, but found that these compounds rapidly disappeared from soil. The problem was taken up in the Bacteriology Department where a large number of bacteria were isolated which could decompose phenol, *m*-cresol, *p*-cresol, *o*-cresol, toluene, and naphthalene, and could utilise these compounds as their only source of energy.(11)

3. *Bacterial Production of Indigotin.*

In the course of the work with aromatic compounds, two organisms were isolated which could oxidise indol to indigotin.(12) These are of some interest to soil bacteriologists as they explain the fate of indol, of which appreciable amounts are added to soil in manure.

Investigations Concerning the Nitrogen-Fixing Bacteria from the Nodules of Leguminous Plants

A large part of the work of the Department has been devoted to this subject. It began with a study, in soil, of the life cycle of the nodule organism which had been investigated in artificial culture by Bewley and Hutchinson.

1. *Life Cycle of the Nodule bacteria in Soil and the Development of Lucerne seed inoculation.*

The nodule organism from lucerne (*Medicago sativa*) when grown in sterilised soil was shown to pass through the same life cycle already found to exist in artificial media. This cycle contains a stage during which the organisms develop flagellae and are actively motile. It was found that during this motile stage the organisms were capable of migrating through Rothamsted soil at a rate of one inch in 24 hours. The addition of minute amounts of calcium di-hydrogen phosphate to the soil along with the bacteria stimulated the production of the motile stage and hastened the migration through soil.(13)

This result was seen to have a bearing on current methods of legume seed inoculation. These in general consisted in wetting the seed before sowing with a suspension of the appropriate nodule bacteria in some liquid. When inoculated seed is sown the bacteria migrate from the seed into the soil and reach the roots, which they infect to form nodules. It seemed clear that the addition of the acid calcium phosphate, by causing an increased motility of the bacteria in the soil, should increase the chances of root infection. Experiment confirmed this expectation.

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(9) H. L. Jensen—"The Microbiology of Farmyard Manure Decomposition in Soil. I. Changes in the Microflora, and their Relation to Nitrification. Journ. Agric. Sci., **21**, 1931, 38.

(10) H. L. Jensen—"The Microbiology of Farmyard Manure Decomposition in Soil. III. Decomposition of the Cells of Micro-organisms." Journ. Agric. Sci., **22**, 1932, 1.

(11)—P. H. H. Gray and H. G. Thornton—"Soil Bacteria that decompose certain Aromatic Compounds." Centrbl. f. Bakt. II, **73**. 1928, 74.

(12) P. H. H. Gray—"The Formation of Indigotin from Indol by Soil Bacteria." Proc. Roy. Soc., London. Ser. B, **102**, 1928. 263.

(13) H. G. Thornton and N. Gangulee—"The Life Cycle of the Nodule Organism. *Bacillus radicicola* Beij., in Soil and its Relation to the Infection of the Host Plant." Proc. Roy. Soc. London. Ser. B. **99**, 1926, 427.

In pot experiments with lucerne the addition of calcium dihydrogen phosphate to the inoculating fluid approximately doubled the number of nodules that were produced. (13)

The new method of seed inoculation thus developed was applied on a field scale to the inoculation of lucerne. Previous attempts at inoculating the lucerne crop in this country had met with indifferent success, although there was reason to suspect a deficiency of lucerne nodule bacteria in the soil over the greater parts of the country. Field experiments, financed by the Royal Agricultural Society and carried out by numerous experimenters, showed a large benefit from the new method of inoculation at most centres outside the South Eastern Counties and proved that good crops could be obtained in most parts of England from inoculated seed. (14) The inoculation of lucerne has now been placed on a commercial basis and some 4,000 acres of inoculated lucerne are sown annually.

2. *Clover Inoculation and the Problem of Strain Competition.*

Recently the more difficult problem of clover inoculation has been studied. This problem was set to us by the Welsh Plant Breeding Station in connection with their attempt to improve the feeding value of upland pastures. On these pastures clover usually does badly.

Examination of the soil from such localities revealed the existence of a strain of nodule bacteria which, though forming large numbers of small nodules, produce little or no benefit to the plant. Similar strains had already been described in America. The presence of these strains in the soils gives rise to a peculiar difficulty affecting seed inoculation with beneficial strains. They tend to prevent the entry of beneficial strains into the plant. This unfortunate characteristic was shown to be possessed by the Welsh inefficient strain.

The problem, therefore, is to find an efficient strain of clover nodule bacteria of sufficient infective virulence to compete against the presence of the inefficient strain. A good strain has been found which is only slightly affected by the presence of the Welsh strain.

The competition effect of the inefficient Welsh strain and the action of this virulent good strain (here called strain A) was illustrated by a sand culture experiment with Alsike Clover in which all the pots were supplied with a mixed flora of local Rothamsted races of clover nodule bacteria while half of them received in addition a suspension of the Welsh inefficient strain.

Where the local nodule bacteria were alone present the nitrogen fixed by the clover averaged 275 milligrams per pot. Where these had to compete against the Welsh strain, nitrogen fixed by the clover added to the sand was reduced to 34 milligrams. Where seed was "inoculated" with Strain A, however, the harmful effect of the Welsh strain was partly overcome and the nitrogen fixed amounted to 112 milligrams. Beneficial results have been obtained in field trials in Wales with Strain A. These results are shown in the following table :

(14) H. G. Thornton—"The 'Inoculation' of Lucerne (*Medicago sativa* L. in Great Britain." Journ. Agric. Sci. 19, 1929, 48.

Effect of Welsh strain and of Strain A on milligrams of nitrogen fixed by Alsike Clover grown in sand.

	Seed not Inoculated	Seed Inoculated Strain A
Sand with only local Nodule Bacteria	275.2	318.0
Sand with local Nodule Bacteria plus Welsh Strain	33.8	111.6

3. *The Infection of the Legume Root.*

Nodules are rarely found on seedlings of lucerne and clover in the cotyledon stage but their appearance is closely associated with the development of the true leaves. Evidence was found that at this stage the roots of the plant secrete some substance stimulatory to the growth of the bacteria. Nodules can indeed be induced to form on seedlings in the cotyledon stage if these are watered with the solution from around the roots of older plants.(15)

The actual mechanism of infection has been investigated. Infection takes place through the root-hairs and is preceded by a characteristic deformation of these hairs. Numerous observations have shown that this preliminary deformation of the root-hairs is necessary to enable infection to take place. It was shown that the deformation was caused by a bacterial secretion and that it could be produced by a cell-free filtrate of the bacterial secretions. It is an interesting fact that the action of the secretions from a given strain of nodule bacteria is not specific to the particular legume species which that strain is capable of infecting. Thus although lucerne nodule bacteria cannot infect clover roots, the secretions of lucerne bacteria can deform clover root-hairs.(16) The nature of the active substance is being investigated. It is thermostable and from the secretions a gum can be precipitated with acetone. In its crude form this gum is also active, but it seems likely that the active substance is some other compound associated with the gum.

4. *The Action of Nitrates on Nodule Formation.*

The study of the root-hair curling has provided an explanation of a phenomenon which had for a long time remained a problem. If inoculated legumes are grown in media rich in nitrates or ammonium salts, nodule formation is harmfully affected and may be stopped entirely.

An experiment in which inoculated lucerne was grown in sand supplied with a range of doses of sodium nitrate, showed that both the number and the size of the nodules were progressively reduced with increasing dosage of nitrate. The nitrate thus produced a twofold effect ; firstly upon the infection by the bacteria and, secondly, upon the growth of such nodules as are formed. These two effects were separately investigated.

(15) H. G. Thornton—"The Role of the Young Lucerne Plant in Determining the Infection of the Root by the Nodule forming Bacteria." Proc. Roy. Soc. London. Ser. B, **104**, 1929, 481.

(16) E. F. McCoy—"Infection by *Bact. radicicola* in Relation to the Microchemistry of the Host's Cell Walls." Proc. Roy. Soc. London. Ser. B, **110**, 1932, 514.

(*a*) *Effect of Nitrate on Root-hair Infection.*

When lucerne was grown in agar containing 0.1 per cent. $NaNO_3$, not only was nodule formation stopped but no infection of the root-hairs took place. This was accounted for by the fact that the nitrate inhibited the deformation of the root-hairs by the bacteria, which is a necessary prelude to infection.

Sodium nitrate at that concentration did not harm the bacteria or prevent them from producing their root-hair curling secretions. On the other hand the bacterial secretions separated from the bacteria by filtration were largely prevented from deforming the root-hairs when these were grown in the presence of sodium nitrate of the above concentration. The results are shown in the following table :

Influence of sodium nitrate upon the deformation of lucerne root hairs by nodule bacteria and by their secretions.

	Percentage of Deformed Root Hairs.
A. Plants grown in Agar without Nitrate.	
1. Plus Nodule Bacteria	80.3
2. Plus Bacterial Secretions ..	71.8
B. Plants grown in Agar with Nitrate.	
1. Plus Nodule Bacteria	14.1
2. Plus Bacterial Secretions ..	12.8

(*b*) *Effect of Nitrate upon Nodule Growth.*

When lucerne plants bearing young nodules were transplanted into a medium containing 0.1 per cent. $NaNO_3$ the growth of the nodules was slowed down or entirely checked. Microtome sections of such nodules showed that the growing cap at the end of the nodule was often walled off by the formation of a layer of cells with thickened walls.

5. *Effect of Nitrate on a Mixed Crop.*

There are so many occasions when legumes and non-legumes are grown in association that the influence of nitrate manuring on such a mixture is of great agricultural importance. A sand culture experiment was made in which three doses of sodium nitrate were applied to (a) lucerne grown alone and (b) lucerne growing with Italian Rye grass.

It was found that the yield and nitrogen content of the lucerne when grown alone were unaffected by the nitrate dose, but where lucerne and grass were grown together, the yield and nitrogen content of the lucerne and even of the combined crop were inversely related to the dosage of nitrate applied because the growth of the lucerne was adversely affected by competition with the more rapidly growing grass.[17]

6. *Uptake of Nitrogen by Grass Associated with Lucerne.*

In the above experiment and in a confirmatory trial, grass growing

(17) H. G. Thornton and Hugh Nicol—" The Effect of Sodium Nitrate on the Growth and Nitrogen Content of a Lucerne and Grass Mixture." Journ. Agric. Sci., **24**, 1934, 269.

with lucerne was found to contain much more nitrogen than was applied as nitrate. This nitrogen must have been derived from that fixed by the lucerne. The uptake of this "fixed" nitrogen by the grass could be detected within three months of sowing. This suggests actual secretion of nitrogen compounds by the lucerne roots.[17,18]

7. *The Equilibrium between Symbiosis and Parasitism, within the Nodule.*

When a healthily growing plant bears nodules produced by an efficient strain of the nodule organism, the relationship between host and bacterium is normally one of symbiosis. A delicate equilibrium exists, however, which can readily be unbalanced in the direction of parasitism.

Such induced parasitism was first observed in the broad bean (*Vicia faba*) on plants grown in boron-deficient culture solution. Such plants bore minute nodules which fixed no nitrogen, while healthy controls bore large and active nodules.

It was found that deficiency of boron had so affected the structure of the nodules that the vascular strands which normally connect the nodule tissue with the stele, were absent or vestigial. In the centre of the nodule the bacteria had become parasitic and had destroyed the contents of the cells in which they lay.[19]

It was supposed that in this case the change to parasitism was caused by the bacteria being cut off from their supply of carbohydrates, normally brought to them along the vascular strands, and to their being reduced to obtaining their energy material from the host protoplasm.

To test this hypothesis, inoculated lucerne plants were placed in the dark so that a deficiency of carbohydrate might be produced, in this case by the stopping of photosynthesis. Nodules from these plants showed parasitic attack on the part of the bacteria quite similar to that shown in boron-deficient nodules.[20]

The change to parasitism which, in these experiments, was induced in young nodules, is a normal phenomenon in old lucerne and clover nodules towards the end of the summer. In such old nodules, parasitism was observed to commence at the base of the nodule and gradually to extend throughout the central tissue until the middle of the nodule was completely decayed.[20] Parasitism is thus an annual phenomenon, tending to extinguish the nor ma symbiotic growth.

THE WORK OF THE GENERAL MICROBIOLOGY DEPARTMENT

D. W. Cutler

The kinds of micro-organisms, both among the bacteria and the protozoa, that occur in the soil, and their activities, are determined by the soil structure ; broadly speaking, the suitability of land to agricultural purposes is correlated with the size of its population, for a soil in good tilth, with ample spaces both within and between the

(18) H. G. Thornton and Hugh Nicol—"Further Evidence upon the Nitrogen Uptake of Grass grown with Lucerne." Journ. Agric. Sci., **24**, 1934, 540. Hugh Nicol—"The Derivation of the Nitrogen of Crop Plants, with Special Reference to Associated Growth." Biol. Rev., **9**, 1934, 383.

(19) W. E. Brenchley and H. G. Thornton—"The Relation Between the Development, Structure, and Functioning of the nodules on *Vicia faba*." Proc. Roy. Soc. London, Ser. B, **98**, 1925. 373.

(20) H. G. Thornton—"The Influence of the Host Plant in Inducing Parasitism in Lucerne and Clover Nodules." Proc. Roy. Soc. London. Ser. B, 106, 1930. 110.

crumbs for air and for water, provides an admirable habitat for bacteria and protozoa. Even where the soil structure is less desirable, and where temporary anaerobicity may occur owing to the cutting off of pore spaces by films of liquid, a large population either of facultative anaerobes, or of spores and cysts will survive.

One of the chief characteristics which makes soil under normal conditions such a suitable home for living cells is the fact that changes when they do occur only take place very slowly, and the inhabitants have time to adapt themselves to the new circumstances and this the free living bacteria and protozoa are very well able to do.

Further, in this, which is one of the oldest of all habitats, the different groups of the community must have arrived at a condition of delicate equilibrium, where any disturbance in one group may seriously influence others, and where drastic changes, either in the chemical or physical environment, may have detrimental effects on the general efficiency of the population in improving soil fertility.

Studies on the soil bacteria have been carried on for a considerable number of years and have been both quantitative and qualitative. Unfortunately the methods of counting these organisms are laborious and in no case entirely satisfactory ; while the indirect dilution methods always give an under-estimation of the numbers, since they depend upon the assumption that all types will grow on one and the same medium at the same time, the more direct methods depend upon the equally unsound assumption that all the cells observed under the microscope are viable. Neither method discriminates between the different physiological groups. Nevertheless, there can be no doubt that both types of method yield valuable results, and that they have thrown considerable light on some aspects of bacterial behaviour both in soils and in cultures. It is firmly established that the numbers of bacteria in field soils change rapidly, and that these changes are to a very great extent independent of environmental conditions. While the general level of numbers is determined by the character of the soil, and largely by the amount of organic matter that it contains, the actual daily or hourly fluctuations seem to arise from intrinsic causes in the organisms themselves. There is, however, some evidence that other things being equal, a high moisture content tends to raise the bacterial numbers, and that a soil temperature of more than 50°F. has a slightly depressing effect, although in the laboratory most soil bacteria grow well at a higher temperature than this.

In the spring and the autumn there is a definite rise in the numbers of bacteria, which again can only be ascribed to intrinsic and not extrinsic causes. It is obvious since the numbers vary so much not only from day to day but from season to season that a single estimation of the numbers of bacteria is of little or no value. Nor is it easy to correlate the numbers of bacteria with the chemical changes that they bring about in the soil. This is for the two-fold reason that under field conditions there are numerous kinds of bacteria, and also many different chemical compounds which because they are constantly changing and inter-changing make a straightforward issue impossible. When, however, a sterilized soil to which a single bacterial species has been added is, for example, given a carbohydrate such as glucose the issue is clear and there is a direct

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correlation between the numbers of bacteria and the amount of carbon dioxide evolved. When the output of carbon dioxide from untreated field soils is considered a very wide range of results is obtained; for example, samples taken from the farmyard manured plot of Broadbalk may give an average daily carbon dioxide production of as little as 0.006 grammes per 200 grammes of dry soil, or as much as 0.022 grammes, although in both cases the average bacterial numbers, as found by the plate method, are twenty millions per gramme of soil. Parallel investigations on such plots as the unmanured, or on plots receiving dressings of minerals with nitrogen as both nitrate of soda and ammonium sulphate, compared with the dunged plot suggest that there are comparatively small differences in the average daily output of carbon dioxide as between plots. Although it may seem a far cry from the heterogeneous community and environment of the soil to the laboratory pure culture, yet work on pure cultures is useful in attacking piece by piece the intricate problem of the soil as a whole. For example, in cultures there is a general agreement between the bacterial numbers and the amount of carbon dioxide produced, but though a rise in numbers is accompanied by an increase in the output of carbon dioxide, yet there is no exact numerical relationship between them, for the individual efficiency of each bacterium varies according to the numbers present in the medium and to their physiological condition. The more bacteria present the less efficient is each individual, and on the whole, they are less efficient producers of carbon dioxide when they are rapidly reproducing. Broadly speaking the same thing is true for efficiency in ammonification, and it seems probable that it applies equally to other chemical activities of soil bacteria.

On the whole work on cultures shows that the soil bacteria are for the most part active fermenters of sugars, both monosaccharoses and disaccharoses, and that they also grow well on salts of the common organic acids. It seems probable that the range of compounds from which one and the same species can obtain carbon, that is, which it can decompose, is a very wide one.

The behaviour of soil bacteria on nitrogen compounds is also characterized by this ability to utilize a wide range of compounds. The same organism may be able to ammonify, to make nitrite from the ammonia that it has itself formed, to utilize nitrite as a source of nitrogen for growth, and to reduce nitrate. The great majority can ammonify to some extent, and there are a fair number that can produce nitrite in small quantities from ammonium salts, both inorganic and organic, while a much larger number reduce nitrate to nitrite, and some carry the reduction further to ammonia, or even to nitrogen.

The question of the formation of nitrite from the various ammonia compounds is again a point on which light has been thrown by laboratory work on pure cultures. It is clear that there is a very much larger number of bacterial species than can produce nitrite in small quantities from ammonia than was previously supposed, and that they can carry out the reaction under very varied environmental conditions, but their behaviour too is variable and the factors that govern it are still obscure. One factor that influences the formation of nitrite and its removal by biological agencies is the carbon-nitrogen ratio. Thus, in cultures, a ratio higher than fifteen to one tends to be accompanied by the disappearance of nitrite without the production of nitrate or ammonia; while lower ratios lead to nitrite formation. For example, the nitrite production in a pure culture after four days' growth when the C/N ratio was half, was 3.2 grammes of nitrite nitrogen per million, while when the ratio was 2 : 1 the amount was 0.15.

From these heterotrophic bacteria the amounts of nitrite produced are small when the medium consists of simple inorganic ammonium salts, but when urine is provided, as the source of nitrogen, the quantity of nitrite formed is very much increased.

In the soil there are considerable quantities of nitrogenous organic compounds, which are probably equally available for the formation of nitrite; but even if this were not the case the numbers in which the nitrite organisms occur are sufficient to ensure the conversion of large quantities of ammonia to nitrite even though the individual contribution may seem to be extremely small.

The elucidation of the problems of soil bacteriology is further complicated by the presence of other micro-organisms; and, from the point of view of their interference with bacterial activities, the protozoa have received more attention than any other group. The soil structure provides a good environment for the life of numerous small amoebae and flagellates, and, in small numbers, ciliates such as Colpoda, are usually found.

More than 250 species of protozoa have been recorded and among these there are twenty-one that have not as yet been recorded from any other locality. There are, however, certain species that are practically ubiquitous, and no soil examined at Rothamsted has failed to yield a protozoan population, though the number of species in any one soil may be small.

Just as the bacteria fluctuate so also do the numbers of protozoa, and again there is no obvious correlation between their fluctuations and the changes taking place in their physical environment. Although apparently the highest numbers of protozoa tend to occur when the soil is both cold and damp, and further, under these conditions, there is the greatest amount of activity. There is, however, a very marked negative correlation between the numbers of bacteria of the types that will grow on nutrient agar plates, and the numbers of active amoebae present in the soil. Whether these amoebae feed indifferently upon all the bacteria that occur in soil, or whether they select among them is still unknown. It is certain that bacteria which are morphologically alike have very different nutritive values, as judged by their effect on amoebic growth, and there is a certain amount of evidence from cultural studies that the amoebae are able to select the food which they prefer. But the problem is very intricate for even when a bacterial species is itself readily eaten by an amoeba, the same bacteria when crushed in the liquid containing the products of their own growth, will inhibit the growth in a culture of the amoebae, and also appear to encourage premature encystment.

Since the majority of protozoa in the soil feed on bacteria, they will by their predactory action tend to keep the bacteria at a higher level of efficiency by actually reducing their density.

The soil then, not only because of its physico-chemical structure, but also from its population presents a very intricate problem. The various members of the community are continually acting and reacting one with another ; the chemical compounds present in the soil are of diverse natures ; the bacterial species are equally diverse, so that at the present time it is almost impossible to disentangle the various end results of the micro-organisms' activities. Only by the laborious process of tracing out piece by piece the work done by the various groups is it possible to hope in the future to obtain a general picture of this, possibly one of the most interesting communities, and further one where the balance of the population is most delicately adjusted.

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THE FARM

It is with great regret that we have to report the death of the Farm Director, Mr. H. G. Miller, on April 5th, 1934. He carried out with great success the reorganisation of the farm, necessitated by the decision to convert it from wholly arable to partly grass and he left it in a satisfactory state for the economic performance of the experimental programme.

His successor as Farm Manager, Mr. J. R. Moffatt, had worked under him for some months so that there was no breach of continuity when the change came.

As far as is feasible without detriment to the scientific work, investigations are made at the farm on matters of practical husbandry.

Three of these are already giving results and are set out below.

COMPARISON OF ELECTRIC MOTOR WITH THE TRACTORS AS SOURCE OF POWER ABOUT THE BUILDINGS

During the last two years there have been facilities on the farm for carrying out routine operations using either a tractor or an electric motor as a source of power. The work is carried out under a grant from the Royal Agricultural Society's Research Fund, and in consultation with the Oxford Institute of Research in Agricultural Engineering. It was made possible in the first instance through the generous donation of electrical equipment by Sir Hugo Hirst, of the General Electric Company, whose agricultural expert, Mr. Rowland, is always ready to help.

In threshing, for example, the electricity consumption is obtained from meter readings immediately before and after an experiment : measurements are taken of the amount of electricity required to bring the thresher up to speed, and also of the electricity used when the thresher is running light, so as to make all necessary corrections.

For the tractors, the quantity of paraffin used during actual threshing is measured, also the petrol required for starting and warming up the engine.

The time required for starting and lining up the tractor is recorded and also that for bringing the motor into position.

In the 1934 threshing experiments the comparison was between a General Electric Company Witton 20 H.P. portable motor and two International Harvester Company 10-20 tractors : one new, and the other having already done 7,000 hours of field work during nearly 7 years of hard service on the farm. The threshing machine, manufactured by Messrs. Marshall & Son (Gainsborough), has a drum width of 48 in., and was run at about 1,100 revolutions per minute.

The work was done under ordinary conditions of farm practice and by the ordinary farm staff : the recording was done by a separate officer. Each test lasted two hours and a considerable number were made. The mean output of grain or total produce in cwt. during that time was on the average :

	Wheat.	Oats.	Barley.
Grain	50	40	40
Straw, chaff, etc. ..	70	55	45
Total produce	120	95	85

The paraffin and electricity consumption and their corresponding costs per ton of grain and per ton of total produce are shown in the following Table :

Per ton of grain.

	Wheat.	Oats.	Barley.	Cost, pence. Wheat.	Oats.	Barley.
New tractor. Gals. ..	1.03	1.48	1.24	7.65	10.8	9.15
Old tractor. Gals. ..	0.94	—	1.28	7.10	—	9.40
Electric motor. Units ..	6.50	7.60	8.40	9.60	11.1	12.4

Per ton of total produce.

	Wheat.	Oats.	Barley.	Cost, pence. Wheat.	Oats.	Barley.
New tractor. Gals. ..	0.45	0.60	0.60	3.29	4.40	4.43
Old tractor. Gals. ..	0.40	—	0.63	3.07	—	4.60
Electric motor. Units ..	2.65	3.20	4.06	3.90	4.73	5.95

The costs were calculated on the basis of 6d. per gallon for paraffin ; lubricating oil 3.75d. per two hours ; and electricity 1.47d. per kWh. (unit charge + fixed charge). The costs for lining up the source of power with the thresher are not included in the above figure, as under commercial conditions starting costs will not occur every two hours : the labour cost in operating the thresher is also omitted since it was the same for the motor and the tractors. Actually so far as power cost is concerned the advantage is with the tractor : but when overhead charges and depreciation are brought into account, as they must be for a complete statement, the electric motor works out as the cheaper source of power. There is at present some uncertainty about the assumptions necessary to evaluate the overhead charges for electricity, and records of upkeep extending over some years will be needed before we can give a reliable figure.

The efficiency of the old tractor is remarkable ; in a number of the comparisons it consumed less paraffin than the new one, presumably because of a better carburettor setting.

The highest overall output recorded for the 20 H.P. motor was only 10.5 H.P. ; the rated output for the tractor is 20 H.P. ; hence it appears that the motor and tractors were only generally used at about half their rated outputs, and more economical results would have been obtained with units of smaller power.

VALUE OF FODDER CROPS

As already stated (p. 30), the value of the fodder crops obtained during the course of the experiments is to be assessed by the pigs since biochemistry is not yet sufficiently advanced to enable us to do this by analysis. It is not proposed, however, to develop investigations into animal nutrition as such.

SHEEP HUSBANDRY EXPERIMENTS

These experiments deal with the flushing of the ewes and other items of management. The four-teated ewe flock is increasing, and is run with the two-teated flock so that the lambs may be otherwise comparable: detailed records are kept of the rates of growth of the lambs to see if the additional teats tend to increase the milk supply.

The interest of the farm staff in experimental work shows itself in the high standard of their ordinary work. As an encouragement to the staff we began in 1933 to send animals to shows, and this has been continued. No special expenditure is incurred on exhibiting, but gratifying successes have been obtained by both farms as the following list shows:

LIST OF SUCCESSES AND SHOW AWARDS, 1933 AND 1934

ROTHAMSTED

Great Hertfordshire Show. Hatfield.

1933. 2nd prize. 5 crossbred fat lambs.
1934. 1st ,, 5 ,, ,, ,,

Hitchin Christmas Fat Stock Show.

1933. 1st prize. 5 crossbred fat tegs.
1934. 1st ,, 5 ,, ,, ,,
1st ,, Fat sow.
1st ,, Pen of 2 bacon pigs.

Smithfield Club's Fat Stock Show.

1934. Reserve and Highly Commended. 3 crossbred fat lambs.

Redbourne and District Agricultural Competitions.

1933. 2nd prize. Horse ploughing (F. Stokes).
3rd ,, ,, ,, (A. Lewis).
1934. 1st prize and silver challenge cup. Horse ploughing (F.Stokes).
1st ,, Best turn-out. Landowners' teams (F. Stokes).
Certificate of National Horse Association of Great Britain (F. Stokes).

WOBURN

Bedford Agricultural Society Show

1933. 1st prize. 5 crossbred lambs.
2nd ,, Large black boar.
3rd ,, Crossbred gilt.
Reserve. 5 breeding ewes.
1934. 1st prize. 5 crossbred lambs.
1st ,, 1 gilt pig.
2nd ,, 5 breeding ewes.
2nd ,, Breeding sow and litter.

Bedford Christmas Fat Stock Show

1934. 1st prize. 3 fat tegs.

Smithfield Club's Fat Stock Show

1933. 1st prize. Crossbred lamb carcase.
Highly commended. Pig carcase (100-160 lb.).

VISITORS TO THE FARM AND LABORATORIES

The number of visitors was 2,460, the highest on record, and the arrangements for demonstrations by Messrs. Garner and Gregory worked out very satisfactorily. The new demonstration room at the farm proved very useful.

INSECT PESTS AT ROTHAMSTED AND WOBURN, 1933-4

H. C. F. NEWTON

GENERAL

There was an increase in wireworm attack this year which was generally severe on cereals. On Pastures field there was an outbreak of *Heterodera schachtii* Schmidt which, together with a frit fly attack, ruined the oat experiment. Gout fly was generally present but less severe than last year. Flea-beetle attack again occurred.

BROADBALK

Wheat. No appreciable loss from insect attack occurred but the infestation by wheat midges (*Sitodiplosis mosellana* Géhin and *Contarinia tritici* Kirby) increased slightly. The following are the figures for the past eight years.

Year.	1927	1928	1929	1930	1931	1932	1933	1934
Percentage grain attack	3.2	6.5	7.7	17.6	21.4	15.4	2.1	4.0

The Wheat Leaf-miner (*Agromyza ambigua* Fall.) was again rare.

HOOS FIELD

The *classical barley* plots, fallowed last year, suffered from wireworm attack, while the Four Course Rotation *barley* was only slightly attacked. The Flea-beetle (*Phyllotreta vittula* Redt.) caused slight leaf damage on both plots, as also did an unidentified Saw-Fly larva. Part of the *alternate wheat* strip was destroyed by wireworm ; wheat bulb-fly was also present.

BARNFIELD

Mangolds. A general attack by the Pigmy Mangold Beetle (*Atomaria linearis* Stephens) occurred, causing some loss of plant. The gappiness was most marked along the upward slope running across the middle of the field. As it has been previously stated that the beetle occurs less frequently on the rape cake area an attempt was made to find out its distribution over the various plots by the examination of about one hundred soil samples. Some five hundred beetles in all were found in these. It appeared that the beetle was fairly evenly distributed over the field, but was less frequent in areas where the tilth was bad and the soil 'capped.' The population was highest on the farmyard manure plots where the soil was more friable, but the mangold plant was much less affected here. It would appear, therefore, that it is a combination of bad growing conditions and beetle attack rather than a larger population of beetles which produced the gappiness on the area referred to. Springtails were also present.

PASTURES

The oat variety trial was partly destroyed by a combined attack of *Heterodera schachtii* Schmidt, frit fly, the stem eelworm (*Anguillulina dipsaci* (Kühn) Gerv. v. Ben) and wireworm. Occasional plants were destroyed by lepidopterous larvae, probably *Apamea secalis* L. Apart from the effect of the *Heterodera* itself, the attack held back growth so that the frit fly attack was intensified, resulting in areas which produced practically no crop. An area similarly infested with *Heterodera* occurred on the commercial oats and a record has been made of both positions. Over the rest of the field few cysts were found except in the case of the wheat experiment, which was lightly infested. Here growth was not affected as in the case of the oats. The roots of two plants from a badly infected area, one plant two feet high and the other only a few inches, were examined and the cysts were counted. There appeared to be little difference in the numbers present ; in the first case some 300 cysts were found ; in the latter over 200.

https://doi.org/10.23637/ERADOC-1-66

Oat crops on Pastures field were in 1929, recorded as "winter killed," and again in 1931, when four acres near the road yielded 14 cwt. per acre.

LONG HOOS

Wheat. Wireworm attack was generally observed on the winter sown cereals. The stem sawfly (*Cephus pygmaeus* L.) was observed ovipositing in early June. *Barley* on the Three-Course Rotation was attacked by wireworm, that on the Six-Course Rotation less than elsewhere on the farm. The Barley flea-beetle (*Phyllotreta vittula* Redt.) was generally present, but did not cause appreciable damage. Frit fly and gout fly attacks were not serious.

Sugar Beet suffered little from insect attack. Some damage by *Plectroscelis concinna* Marsh, and by Springtails occurred on LONG HOOS I. The *beans* on the same section were severely attacked by the pea and bean weevil (*Sitona lineata* L.). On the *flax* the Flea-beetle (*Apthona euphorbiae* Schr.) was found but numbers were too small to cause damage.

FOSTERS

One sowing of *kale* was destroyed by Flea-beetles in early May, the second sowing (May 10th) escaped. Later, in early June the third sowing and the resown first plot were subject to a fresh attack.

GREAT HARPENDEN

Rooks destroyed the first sowing of beans in the north-east of the field.

WOBURN

STACKYARD

Barley was attacked by gout fly. Slight damage to *Sugar beet* was caused by wireworm, Pigmy Mangold beetle and Mangold fly (*Pegomyia hyoscyami* Panz.). Odd plants were eaten off by rodents. Mangold fly was also present in Butt Close.

LANSOME

Maize suffered from frit fly attacking the tillers, as many as twenty larvae occurring on one plant. Some flea-beetle damage occurred on the cruciferous crops and the *swedes* were attacked by cutworms.

FUNGUS DISEASES AT ROTHAMSTED AND WOBURN, 1933-34

MARY D. GLYNNE

WHEAT

Take-all (*Ophiobolus graminis* Sacc.) was rare. It is generally found on the Continuous wheat and barley experiments on Stackyard field, Woburn, but this season these were fallow.

Foot Rot (mainly *Fusarium culmorum* (W.G.Sm.) Sacc.) was found scattered as occasional "whiteheads" through several crops at Rothamsted, there being more on Broadbalk than on other fields. At Woburn it was plentiful on the "Precision" and on the "Nitrogenous Manure" experiments on Butt Furlong field, dead heads and stunted plants being common. Similar symptoms had been apparent in barley grown in the same field in 1929 when patches of stunted barley were associated with the presence of *Fusarium* sp. on the underground parts.

Yellow Rust (*Puccinia glumarum* (Schm.) Erikss. and Henn) was very rare in the hot dry summer of 1934. In normal years it appears in June and by July is found on most of the wheat crops, its incidence varying from slight to plentiful. In 1934, however, none was found before July; it was never more than slight on any crop at Rothamsted or Woburn; in some plots only one affected leaf and in many no trace of the disease was found.

Brown Rust (*Puccinia triticina* Erikss.) which in most years is slight in July, was not found at all.

Mildew (*Erysiphe graminis* DC.) was much more abundant than usual. It appeared in June, and by July, though still slight in some plots, was generally plentiful. An eye estimation of its incidence on Broadbalk showed a tendency for the disease to increase with the supply of nitrogenous manure. Differences in the amount of disease noticed in the strips fallowed in different years may have been due to their position in the field, or to the effect of fallowing. Mildew appeared rather more plentiful at Woburn.

Loose Smut (*Ustilago Tritici* (Pers.) Rostr.) was found, but was uncommon at Rothamsted and at Woburn.

OATS

Were grown only on Pastures field at Rothamsted.

Leaf Spot (*Helminthosporium Avenae* Eid.) was moderate in incidence.

Mildew (*Erysiphe graminis* DC.) varied from slight to plentiful in different parts of the crop.

BARLEY

Leaf Stripe (*Helminthosporium gramineum* Rabenh.) was scarce and only secondary infections were found.

Net Blotch (*Pyrenophora teres* Drechsl.) was very uncommon. The scarcity of these two diseases was noteworthy as they have been considerably more plentiful in other years.

Leaf Blotch (*Rhynchosporium Secalis* (Oud.) Davis) was not found in 1933 or in 1934 though it has been fairly common in previous years.

Mildew (*Erysiphe graminis* DC.) was moderate in quantity on most of the barley crops.

Deficiency Symptoms. All plots which receive no phosphate in the Continuous Barley experiment on Hoos field showed striking symptoms of phosphate deficiency in the middle of May. Affected plots were readily distinguished at a distance from the others by their paler colour. The leaves were found to be withered at the tips with red colouration in the lower parts of the plants. After about six weeks new young leaves had grown and the signs of deficiency were no longer obvious.

RYE

Brown Rust. (*Puccinia secalina* Grove) was found at Woburn in mid-July, its incidence being slight.

Mildew (*Erysiphe graminis* DC.) was moderate to plentiful at Rothamsted and Woburn.

GRASSES

Black Stem Rust (*Puccinia graminis* Pers.) was found in the autumn on wild grasses present as weeds among the mangolds on Barnfield.

Choke (*Epichloe typhina* (Fr.) Tul.) varied in its distribution from plot to plot in much the same way as last year. It appeared, as it usually does, mostly on *Agrostis* and to a less extent on *Dactylis glomerata*. There was rather more on the latter host than in the previous year. The disease was most plentiful on plots which had received ammonium sulphate and were fairly acid, and was less on those treated with lime. *Agrostis* was also most plentiful on these plots. There appeared to be a slight increase compared with the previous season in the incidence of the disease on the unlimed parts of plots 8 and 15 and on the lightly limed parts of plots 19 and 20. Eggs and larvae of the dipteron *Anthomyia spreta*, Meig., were, as usual, found on the fungal stroma.

CLOVER

Rot, (*Sclerotinia Trifoliorum* Erikss.) Bare patches and dead plants were present both at Rothamsted and Woburn early in the season but the fungus was not obvious till the autumn when severe attacks were noted in Pastures field Rothamsted, and on Series D on Stackyard field, Woburn. Late in the autumn it was also common on the six-course rotation experiments at both stations.

Downy Mildew (*Peronospora Trifoliorum* de Bary) was generally moderate and was plentiful on Alsike clover in the six-course rotation and in Series D, Stackyard field, Woburn.

LUCERNE

Downy Mildew (*Peronospora Trifoliorum* de Bary) was found rarely on the excellent crop on Lansome field, Woburn.

BROAD BEANS

This crop was grown only at Rothamsted on Great Harpenden, Long Hoos and Little Hoos fields.

Chocolate Spot could not be found and Grey Mould (*Botrytis cinerea* Pers.) was uncommon contrasting with the previous year when both these diseases were plentiful.

POTATOES

Appeared on the whole healthy though a little virus was seen at Rothamsted and rather more at Woburn.

Blackleg (*Bacillus phytophthorus* Appel.) was found but rarely at Woburn.

Blight (*Phytophthora infestans* (Mont.) de Bary) occurred on the foliage in early October appearing to be slight at Woburn and moderate in incidence at Rothamsted.

Early Blight (*Alternaria Solani*, (E and M) Sorauer, emend. Jones and Grout) was abundant on the leaves which were still green in early October both at Rothamsted and Woburn. This has not been observed in previous years.

SUGAR BEET

Blackleg (*Phoma Betae* (Oud.) Frank or *Pythium* sp.) was fairly common on seedlings at Rothamsted and at Woburn in May.

Crown Gall (probably *Bacterium tumefaciens* E.F. Sm. and Towns.) was well developed on a few roots at Rothamsted.

Rust (*Uromyces Betae* (Pers.) Tul.) was slight to moderate on most crops and rather plentiful in parts of Long Hoos manurial experiment.

Leaf Spot (*Cercospora beticola* Sacc.) appeared on occasional plants.

Leaf Scorch associated with *Alternaria tenuis* Nees was moderately plentiful.

MANGOLDS

Blackleg (*Phoma Betae* (Oud.) Frank or *Pythium* sp.) was found occasionally on seedlings in Barnfield in May.

Rust (*Uromyces Betae* (Pers.) Tul.) varied from slight to fairly plentiful in different plots.

Downy Mildew (*Peronospora Schachtii* Fuck.) was found on one or two plants on Long Hoos.

Leaf Spot (*Cercospora beticola* Sacc.) appeared on occasional plants.

Leaf Scorch associated with *Alternaria tenuis* Nees varied from absent to moderate on different plots in Barnfield.

Mosaic was very scarce, only about fifteen affected plants being found in the whole field of 8 acres. This afforded a great contrast to the previous season when the percentage of diseased plants varied from 3 to 70 per cent. in different plots, having obviously spread from centres of infection. The difference in incidence of the disease in the two seasons probably depended on weather conditions which in the hot dry season of 1934 were unfavourable to the development of the insect vectors, the chief agents in spreading the disease.

Deficiency Symptoms

A type of scorch beginning with a black spotting of the leaves followed by a dark brown to black scorching of the edges was very plentiful on certain plots and absent from others in Barnfield at Rothamsted by October, an eye estimation indicating that in the badly affected plots more than half the plants were affected. Microscopic examination showed no signs of fungal or bacterial parasites. A survey showed that the symptoms were most marked where potash was deficient and nitrogen plentiful in the manurial applications, and that their distribution in different plots was consistent with the hypothesis that the scorch was due to potash deficiency. Notes on its incidence have been made in other years. There was some indication of an inverse relationship between the incidence of rust and of this type of scorch.

SWEDE

Club Root (*Plasmodiophora Brassicae* Woron.) with the usual symptoms occurred in patches varying from moderate to plentiful in the upper part of Stackyard field, Woburn. A brown dry rot, beginning near the base of the bulb and spreading upwards was found attacking swedes on Lansome field in moderate quantity. No galls were found and at first the disease was not thought to be Club root. Microscopic examination, however, showed the organism (*Plasmodiophora Brassicae* Woron.) present in healthy-looking flesh. This was therefore assumed to be the primary agent in rotting, with wound parasites such as *Rhizoctonia* sp., saprophytic eelworms and boring insects acting as secondary agents.

Soft Rot (possibly *Bacillus carotovorus* L. R. Jones) was found in moderate quantity on Lansome field, Woburn, in the early autumn and increased considerably in the late autumn.

Downy Mildew (*Peronospora parasitica* (Pers.) Tul.) was plentiful in October at Woburn. In Butt Furlong field where kale and swedes were mixed the leaves of the latter could be identified by the abundance of the disease on them while the kale was free as late as October, though two months later the kale was also attacked.

Deficiency Disease

Brown Heart. Symptoms resembling " Brown heart " were found occasionally on Lansome field, Woburn.

KALE

Was very healthy in the early part of the season and showed little or no sign of disease until the late autumn.

Downy Mildew (*Peronospora parasitica* (Pers.) Tul.) appeared in the winter at Rothamsted and Woburn in moderate quantity.

Grey Mould (*Botrytis cinerea* Pers.) was moderate at Rothamsted and slight at Woburn in the winter.

White Blister (*Cystopus candidus* (Pers.) de Bary) and *Alternaria Brassicae* (Berk.) Bolle were found occasionally.

BRUSSELS SPROUTS

Very healthy early in the season.

Grey Mould (*Botrytis cinerea* Pers.) was present on the outer leaves and a Soft Rot (bacterial) was occasional, in the autumn, at Rothamsted.

CABBAGE

Ring Spot (*Mycosphaerella brassicicola* (Fr.) Lindau) was moderate and *Alternaria Brassicae* (Berk.) Bolle occasional in the autumn at Rothamsted.

CARROTS were grown only on Lansome field, Woburn.

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

Sclerotinia Rot (*Sclerotinia sclerotiorum* (Lib.) de Bary) appeared in the clamp in moderate quantity.

Soft Rot (*Bacillus caratovorus* L.R. Jones) appeared in the clamp, about 10 per cent. of the roots being affected to some extent.

FARM REPORT, 1934

Weather

The year, October, 1933, to September, 1934, was abnormally dry and hot, rather similar to the previous one. The rainfall totalled 19.16 inches, 3.32 inches below last year's figure and 9.40 inches below the 81-year average. The biggest deficit occurred in the last three months of 1933, when only 3.49 inches were recorded against the 80-year average of 8.38 inches. There was, however, one very wet spell at the end of February and early in March, which stopped all land work for almost three weeks. The four summer months, May to August, were dry, and gave a deficit of almost 4 inches compared with a corresponding deficit last year of almost 5 inches. In nine of the twelve months the rainfall was below the average, and the biggest increase over the average which occurred in March, was only ½ inch. Frequent showers occurred in August, which rather interfered with the harvest.

The total sunshine for the year amounted to just 40 hours above the average of 1,561 hours, but 210 hours less than 1933. The last three months of 1933 gave a deficit of 29 hours. July was hot, and provided 74 hours sunshine above normal.

The mean temperature for the year was about 1°F. above the normal of 48°F. December was very cold and dry, with severe frosts. July gave an average temperature of 3.5°F. above normal.

The weather of 1934, although generally similar to 1933, was drier but less sunny, and the monthly fluctuations of both sunshine and temperature were greater than in 1933.

Weather and Crops

The three dry months, October to December, 1933, enabled root-lifting and carting, and the sowing of winter corn to be carried out under good conditions,

The continued dry weather and frosts made the ground under winter corn very puffy. This encouraged wireworm, but heavy ring-rolling prevented the attack from becoming serious.

The hot and dry summer proved very suitable to the flea-beetle, and one strip of kale in Fosters field failed after three sowings. Other parts of the field became patchy, but the plants grew away with the late rain and further applications of sulphate of ammonia. Where the plant was thin the individual kale plants attained greater size, so that all the ground was covered.

The year was very favourable for charlock, and much of it had to be hand pulled. No infestation was sufficient to warrant the ploughing up of any crop.

In Long Hoos the seeds experiment failed, and a similar experiment was laid down under oats in Pastures field. Here a heavy seeding was given and the plots have taken well.

This year harvest operations began on July 30th, but considerable interruption was caused by the showers. All corn was stooked after cutting, and was carted later in good condition. A little of the wheat was threshed out early and sold for seed.

Classical Experiments

Broadbalk was sown on October 17th, section IV being fallowed. The section fallowed in 1933 showed up distinctly in spring as a greener and more luxuriant growth. At harvest only a few of the heavier plots were laid, and little damage was done. The stubble was cleaner than it has been for several years. Poppies were almost entirely absent and slender foxtail (*Alopecurus agrestis*) was not nearly so prevalent as usual.

Hoosfield barley plots were sown this year after the fallow in 1933. Sowing took place rather late, as a result of the heavy rainfall early in March. The narrow six-inch spacing was reverted to and only the one variety—Plumage Archer—was sown. The individual plots did not show up so distinctly as in previous years, as the effect of fallowing was to even out the plot differences. The only two strips which were noticeable were those without superphosphate. On these plots the leaf tips turned brown early in the year but the plant recovered later ; these plots came into ear about ten days later than the other plots. The stubble quickly became green after harvest, and a surface ploughing was done to bury these weeds and to encourage others to germinate. The surface was periodically worked until the winter ploughing, when the germinated weeds were buried.

Barnfield was ploughed up by November 17th, and so received the benefit of the December frosts. The wet spell early in March made it impossible to work the land, and the tilth at sowing time was rather coarse. Germination was poor except on the dunged plots, and damage was done by the Pigmy Mangold Beetle (*Atomaria linearis*). Growth was slow during the early summer, but the roots grew away well later and the average yield for the whole field was over 20 tons per acre. The field is now badly infested with couch grass (*Agropyrium repens*). The heaviness of the soil and the small period of time available for cultivating the land before sowing in spring, makes it difficult to keep the weed in check.

In Agdell the seeds undersown in the barley failed, and the field was ploughed up and sown with spring beans. The central strip, which receives mineral manures only to the root crop, had the best plant. The middle and lower strips (M and O) were badly infested with coltsfoot.

Park Grass plots were given a more severe harrowing than usual, early in the year, and the plots were rolled after the application of the manures. The hay was made in good condition. Only very few of the plots made sufficient growth for a second cut, but the mower was run over all plots to remove what growth there was, so that the spring growth would not be retarded.

The half-acre wheat after fallow in Hoosfield was attacked by both wireworm and wheat bulb fly (*Hylemia coarctata*). The resulting plant was rather thin, but all the ground was covered.

The exhaustion land in Hoosfield was sown with barley after last year's fallow, and yielded 22 cwt. per acre. The old manurial strips, last manured in 1901, could easily be detected.

Modern Long-Term Experiments

Four-course. The potato series looked very backward throughout the season, although there was no severe attack of any disease. The slight attack of blight, however, was not sufficient to account for the poor appearance of the crop, and the stock of seed was the same as was used in the other experiments. The average yield of $3\frac{3}{4}$ tons per acre was considerably less than in previous years, but all the tubers were perfectly healthy and kept well.

The plot in the seeds break which had the straw applied on the surface, yielded very badly again this year. In future, to avoid this killing of the plant by the straw, all organic manures are to be ploughed in after harvesting the barley and pure rye grass will then be sown.

Six-course. The clover break failed for the third successive year, in spite of the heavy seeding. A fair plant was present during the winter months, but this disappeared in the spring. There was no severe attack of disease. *Sclerotinia trifoliorum* was present in small amount, but not sufficient to cause complete failure of the clover. It is proposed to sow a strip of inoculated seed next year on an adjoining piece of land to see if this improves the " take " of the clover.

The forage mixture contained very few beans or vetches, as they were crowded out by the rapidly growing rye. Since the start of the rotation the mixture has been predominantly rye, and this year it was decided to treat it as a rye crop and harvest the mature grain. In future rye alone will be sown, and harvested as a grain crop.

Three-Course (Straw and Green Manure). The only noteworthy feature was the sugar beet plots following rye ploughed-in. The beet on these plots were much less forward and the leaves were more yellowed than those following either of the other two green manure crops. The mean yield on these plots was also lower.

Three-Course (Cultivation). The wheat stubble became very weedy after harvest, and both the rotary and tine cultivation done for mangolds in spring left the weeds on the surface, and they soon took root again. On these cultivated plots it was difficult to pick out the rows of mangolds, long after those on the ploughed plots were showing well. The predominant weed was Slender Foxtail (*Alopecurus agrestis*), and the whole area had to be carefully hand-hoed as soon as the rows could be picked out. In the wet spring the weeds rapidly covered the ground and smothered the plants before the rows showed sufficiently well to enable hoeing to be done. The mean yield of all the plots this year was almost 36 tons per acre.

Annual Experiments

Sugar beet. Kleinwanzleben E seed was used for the annual experiments this year. The variety Kühn previously used was retained in the rotations to maintain continuity. Although Kühn was sown and singled before Kleinwanzleben E, the latter made much more vigorous growth and gave better yields. All roots grew well after a rather late and slow start, and the mean yield of the two experiments was 14 and 15 tons of washed beet per acre with sugar percentages of 17 and 18.

Potatoes. The variety Ally was again sown this year. The crop grew well throughout the year and was almost entirely free from disease. Several of the plot yields reached 13 tons per acre, with a very low proportion of seed and chats.

Brussel sprouts. The plants were not set out until June 8th, as we had to wait for rain. Hand watering had to be resorted to, to give them a start, but they grew away well and yielded three pickings, the first on October 24th. The quality of the sprouts was excellent, and the yield of 90 cwt. per acre was much above last year's figure.

Wheat. The experiment to determine the effect of top dressings of sulphate of ammonia applied at different times throughout the growing period, gave no significant result. The mean yield of all plots receiving nitrogen was 37 cwt. per acre, those unmanured yielding 35 cwt. per acre.

Beans. This year, for the first time, a manurial experiment on beans was included in the experimental programme. The autumn sowing was destroyed by birds and the plots were resown early in February. The only significant responses were to the two levels of dung. The mean yield of the higher dung level (15 tons per acre) was just over 20 cwt. per acre.

Cropping, 1933-34

It was the turn of Fosters field to be dunged for kale this year. Half the field was dressed in autumn, 1933, and the rest in the following spring. The field was drilled in strips from the north. The first sown strip was destroyed by the flea-beetle three times. Before the second and third sowings the seeds were soaked in turpentine and paraffin rags were dragged across the crop. This strip was eventually sown broadcast with rape and winter green turnips and a fair yield of green food was provided.

In previous years part of the field to be cropped with kale was sown in the autumn with rye, to provide keep for the ewes and lambs in April. This was folded off and the kale sown. In 1932 the kale following the rye was much poorer than the rest of the field, and in 1933 the corresponding area was more severely attacked by the flea-beetle. The probable explanation of this is that the tilth for kale after folded rye is much coarser than on the uncropped area; hence the plants took longer to germinate and subsequent growth was slower. The same difficulty in providing a suitable tilth after folding is experienced for barley after folded kale.

Pastures field was sown with our own seed of Marvellous spring oats in mid-February. Drilling took place in both directions. The crop made good progress at the start but later became badly infected with oat eelworm (*Heterodera schachtii*). The plant became thin, and certain areas were almost completely destroyed. The sparsity of the plant enabled knot grass (*Polygonum aviculare*) to gain a firm hold, and this smothered out most of the undersown seeds on the north side. The oats were thicker on the south side of the field, and the experimental strips of seeds mixtures made good growth. Carting of the oats had to be delayed until the weeds in the sheaf butts were withered. After the field was cleared the stubble was broken up, the weeds harrowed and horse-raked together and burnt. The north side of the field was dunged in the autumn ready for kale in 1935.

No satisfactory control measure against the eelworm is yet known, and at present the only way to prevent a recurrence of the attack is to give the field a long rotation to ensure that oats are not sown again for at least eight years. A small experimental area of oats will be sown next year to test the effect of various soil fumigants on the eelworms.

Harpenden field was sown with winter beans, but rooks, game, and frost did considerable damage to the crop. Most of the field was redrilled in spring, but again severe damage was done by birds and the plant became thin. Much hand and horse-hoeing had to be done to keep the field reasonably clean and about two acres of headland were ploughed up. Spring beans were also drilled on the site of the 1933 brussel sprouts crop, so that the whole field was under the same crop. The final yield was 13 cwt. per acre. Ewes were run over the stubble after harvest, and the field was then thoroughly cultivated and ploughed up for wheat. The tractor thistlebar was used on the field before sowing wheat to kill any self-sown beans.

Little Hoos was sown with Victor wheat following beans, and yielded an excellent crop of 32 cwt. per acre. The only manure given was a top dressing of 1 cwt. of sulphate of ammonia per acre, and in spite of the heavy crop no lodging took place.

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The 1½ acres of Victor wheat in Pennell's piece was very badly laid and damaged by sparrows. Most of the crop had to be cut with the mower and carted loose.

Great Knott was sown with barley following kale. The west side of the field was folded and the rest cut and carted. Ewes were run over the cut stalks to clean up the stems and fallen leaves. The field was ploughed in March, but considerable difficulty was experienced in getting a suitable tilth. No manure was applied, and the crop yielded 25 cwt. per acre.

Long Hoos was set aside for the annual experiments which are described elsewhere. The site of the seeds experiment which failed was sown with linseed in mid-May. The dry weather made germination very slow and three distinct germinations took place, each after a slight shower of rain. The crop consequently ripened unevenly, and when it was cut many of the bolls were quite green. The yield was 9½ cwt. per acre.

In May, 1934, a further seven acres of arable land, now called Harwood's piece was taken over. The field had not been under cultivation for over two years and was covered with couch grass and docks. Cleaning operations were done throughout the summer, but it will be some time before the field is really clean. It will be cropped with kale next year, so that horse-hoeing can be done throughout the summer.

Grassland

The grass made fair progress in the spring, and although the pastures became very bare later in the summer they did not appear so scorched as in the previous year. A further 59 acres of old grassland were taken over in the early summer, and although the quality was poor and growth was slow, the field provided very valuable keep at a time when other pastures were nearly bare. Next year manurial trial strips will be laid down to determine the best way to improve the field. Store cattle will be outwintered there during the coming winter.

The fields which carried sheep through the winter were shut for hay early in the year. In spite of the drought the hay made fair growth and final yields were satisfactory. The failure of last year's hay crop resulted in our stock of hay being almost spent after the winter feeding, and it became necessary to buy in two stacks of cheap hay for the outwintering cattle.

The grassland has been overstocked for the last few years, and during the grazing season the fields quickly became bare and stale as they were rarely rested. Hay crops were also poor, as the fields were grazed quite late in the spring before being shut. At present the grass is carrying about one ewe per acre, and this figure we shall be able to maintain.

No real cultivation other than topping in summer has been given to the grassland for several years. This year the fields were harrowed in spring and topped in summer. Moss has made an appearance in many of the fields, and a severe annual harrowing will be done in future to keep this in check.

Livestock

Horses. Two four-year-old Suffolk geldings were purchased privately in summer, and one old horse has been sold. The increase in the number of horses to six is necessary to keep pace with the expansion of the experimental programme.

Pigs. The satisfactory results of the first pig experiment, the account of which appeared in the last Report, led us to conduct a further experiment this year. The experiment was designed to obtain information on the effects of different levels of nutrition. The highest level was *ad lib.* feeding, which was compared with three lower levels. The lowest level proved to be too low, but a comparison of the other three levels showed no significant economy in food consumption of any one level over any other, although *ad lib.* feeding feeding tended to be more wasteful of food during the latter stages. So with equal food utilisation, *ad lib.* feeding would give the best results, as pigs on this level would reach selling weight earlier, thus giving more rapid capital turnover.

During the first contract period (November-March, 1934), 123 bacon pigs were delivered to the bacon factory from the two farms, and 340 pigs during the second contract period (April-December, 1934). The following table gives the percentage grading returns for the two farms separately.

GRADING RETURNS

(1*st Contract*)

	Total pigs delivered.	Grade A.	Grade B.	Grade C.	Grade D.	Grade E.	Ungraded.
Rothamsted	50	14	56	24	6	—	—
Woburn ..	73	25	48	20	7	—	—
			2nd Contract				
Rothamsted	168	24	42	17	15	1	1
Woburn ..	172	17	32	17	21	—	13 *

* Due to pigs being delivered slightly under weight.

The Rothamsted figures include the pigs from the two experiments, a large proportion of which graded C and D.

During an early hot spell in May we had an attack of swine erysipelas and several deaths occurred among the fattening pigs. All the pigs on the farm were inoculated and no further trouble was experienced.

Several weakly litters of pigs were produced during the year, and as this was thought to be due to the ageing of the boar used, a new young Large White boar was bought. The new boar is giving good and large litters.

All seed, chat and rejected potatoes were fed raw to the sows outside during the winter and they appeared to relish them. The general condition of the sows on being brought in to farrow was improved as a result of this extra feeding and no harmful results were apparent.

All fattening pigs are now given dry meal at the commencement of each feed and water is added after about ten minutes. This method of feeding has improved the belly measurements of bacon pigs, and it prevents the pigs overloading their stomachs with cold water.

Cattle

The policy during the year has been to reduce the numbers of cattle. The cows, which were used to rear calves intensively, were sold during the year as they calved. Six Shorthorn heifers from a well-known herd were bulled to calve in the early Spring of 1935. With their calves they will be kept outside during the summer without supplementary feeding, and the calves will be weaned into covered yards in the autumn.

The fattening cattle were not hurried on during the summer as we wanted them to qualify for the payment from the Cattle Fund. The price of beef, however, has fallen so low that it more than counter-balances the payment from the fund.

Sheep. The work started in 1931 has continued along previous lines. The best of our Half-bred ewes were again mated with a Scotch Half-bred tup this year to produce ewe lambs for breeding. We now have 42 of these lambs born in 1932, 30 born in 1933 and 18 born in 1934. Up to the present it has been impossible to make any direct comparison with Scotch Half-bred ewes as both farms were stocked to capacity. This year, however, with the culling of several old ewes it has been possible to buy in 50 Scotch gimmers. Of these 35 are at Woburn together with 15 Rothamsted bred gimmers, while 15 of each breeding are at Rothamsted. Two direct comparisons will now be made under slightly differing conditions of management.

The 4 teated ewes were again put to a tup possessing 4 teats. Although most of the ewes milk in all four teats after lambing we have, as yet, found no indication that their lambs make use of the extra teats as no superiority in weight is shown at 6 or 18 weeks, over those lambs from normal 2-teated ewes. Unfortunately this year' owing to scarcity of triplets it was not possible to get any of these ewes to rear three lambs.

The attempt to breed from ewe lambs was continued. 49 were put to the tup in 1932, 60 in 1933, and 38 in 1934. Of these only 13, 29 and 25 lambed. It remains to be seen whether the ewes which lamb as hoggs will make better mothers than the others.

Experiments to determine the best methods of flushing ewes are being continued. The results of the first two years have shown no significant increase in the number of lambs from the flushing treatments. A further experiment was started in 1934 with more intensive treatments than previously, and a shorter time elapsed before turning in the tups.

Twenty-eight of the Rothamsted flock were mated for lambing in January this year, to cater for the early market; 41 lambs were born and reared. The main lambing commenced early in March and the final figures give a lambing percentage of just under 150. There was a marked scarcity of triplets, only two being born throughout the lambing. This occurred on other farms and was attributed by the shepherds to the bare and scorched condition of the pastures at tupping time. About 50 old ewes were culled from the flock during the summer, the best of which were sold in lamb.

Electrical Investigations. An account of this work is given separately on p. 69.

Estate Work

Since the purchase of the Estate the farm has undertaken most of the extra work entailed. The new boundary fence in High Field has been creosoted, Barnfield pond has been cleaned and fenced in, and many of the gates and fences have been repaired.

Buildings

There have been no structural alterations during the year other than new windows to the experimental pig pens. A scheme for a new piggery in place of the converted army huts at present in use, is under consideration.

Successes at Shows

A detailed list of awards secured at national and local shows in 1933 and 1934 is given on p. 71.

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.
R. A. Lister & Co., Ltd.	Oil engine, Sheep shearing machine
Miller Wheels, Ltd.	Tractor wheels.
G. Monro, Ltd.	Simar rototiller and motor hoe.
Parmiter & Sons, Ltd.	Rake & harrows.
Ransomes, Sims & Jefferies, Ltd.	Ploughs, cultivators, drills, grass rejuvenator.
Ruston, Hornsby, Ltd.	Grain drill, binder.
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.

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 anemobiagraph; *Rainfall*—5-inch gauge taken at 9 a.m. 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.

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 deposits of solid matter from the atmosphere at Rothamsted are among the lowest in the country; for the year ending March, 1934, they amounted to only 303 lb. per acre. No other station obtained a lower figure for the year.

DEVIATIONS FROM MONTHLY AVERAGE VALUES. OCT. 19 33—SEPT. 1934.