Rothamsted Report for 1946

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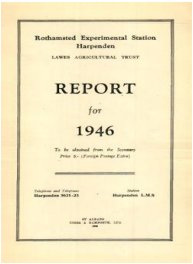

Departmental Reports

Rothamsted Research

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DEPARTMENT OF PHYSICS

By R. K. SCHOFIELD

STAFF

During the year Dr. Keen was seconded on two occasions for duties overseas. At the invitation of the Palestine Government he visited Palestine to report on agricultural policy and on soil conservation, and to formulate proposals for the administrative organisation needed (1). Later in the year, at the request of the British Government, he went to West Africa as Chairman of a Government mission to inquire into the production of vegetable oil and oil seeds (2).

In Dr. Keen's absence Dr. Schofield acted as head of the department. Dr. Antonio Teixeira returned to Portugal in August, 1946, having obtained the Ph.D. degree. Mr. Oscar Talibuddin has worked throughout the year as a voluntary worker.

FIELD WORK

Deep ploughing experiments

This series of field experiments has been continued for a second year in an enlarged form. Fifteen centres were started in the autumn of 1944 and a further 15 in the autumn of 1945. The ploughing and cultivation treatments compared were shallow ploughing, about 7–9 in., with and without subsoiling to about 13–15 in., and deep ploughing, about 13–15 in., with and without subsoiling to 18–20 in. In addition on some fields an extra treatment, ploughing to 11–12 in., was also added. Of the fifteen experiments started in the autumn of 1944 fourteen were cropped with potatoes, and at harvest it was found that depth of ploughing, or the presence or absence of subsoiling, had no effect on the yields taken as a whole. In detail, deep ploughing had not depressed the yield on any field appreciably, whatever the subsoil, provided an adequate supply of fertiliser was given, and it probably increased it on one very badly drained field.

Fourteen of these fields went into corn in 1945–46, having received shallow cultivations only after the potatoes. Since the harvest was very difficult, yields could only be determined on ten of these fields, and the results were that the yield of winter wheat was between 1–2 cwt. higher on land ploughed to 12 in. or over, or subsoiled to 12 in. or over for the potato crop, and this effect was usually more noticeable on the heavier lands.

Nine of the fields of the second series were in potatoes in 1946, having received the same ploughing and subsoiling treatments in the autumn of 1945 as the first series received in 1944. The results were also the same: no matter what the subsoil, the potato yields were independent of depth of ploughing. Four of the fields were in sugar beet. They received the same ploughing treatments as the potatoes, but in three of them an additional comparison was made between ploughing the mineral fertiliser down with putting it

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in the seed-bed. The results were that yields were not affected by any of the ploughing treatments, but it is just possible they were slightly increased by ploughing in the fertiliser.

Arrangements were made during the summer for a third series to start in the autumn of 1946.

Effect of cultivation on the root development of the crop and on the physical properties of the soil

The comparisons of root systems, soil moisture and air contents under different methods of cultivation were again made at several centres. Some time had, however, to be spent in finding a quicker and more reliable method of determining air contents than that previously used. The results were similar to those of the previous year and the methods employed did not show that any of these properties was appreciably affected by the different cultivation treatments.

The tendency noted on a few fields in the spring of 1945 for root penetration to occur more rapidly on the deep than on the shallow ploughed plots did not persist into the summer, nor was it observed again in 1946.

An experiment was carried out on Great Knott, Rothamsted, on the effects of depth of cultivation between the rows of potatoes; the effects of earthing up or not earthing up; and of straw mulching between the rows. The total crop yield and percentage ware showed no significant differences under the different treatments.

The crop was sampled at harvest and the ware sorted to determine the incidence of greening, blight, scurf and scab. The extent of the last three of these troubles was independent of cultivation treatment. The amount of greening was reduced appreciably by earthing up, but was as high under the straw mulch as on the plots that were not earthed up. It is intended, however, to repeat the experiment on similar lines in 1947.

Evaporation and transpiration

The third summer of experiments round the pit in the meteorological enclosure has not added much to existing knowledge because of the unfavourable weather (see p. 25). It was hoped that with a water table maintained at 36 in. below a turf surface some evidence of root range might be obtained, but there was always sufficient rain to ensure that the grass was never short of water whatever the depth of the water table. The experiment has given a convincing demonstration of the lack of any precise meaning in "transpiration ratio". Of three turf surfaces, two date from the spring of 1944 and have been unfertilised, and the third dates from the spring of 1945 and was given a heavy dressing of ammonium phosphate. Transpiration from all three during the summer of 1946 was, very nearly, the same: the crop yields were 29 and 28½ cwt. per acre for the unfertilised, and 71 cwt. per acre for the fertilised surface. With other evidence the present indication is that transpiration from grass under British conditions is largely a weather phenomenon, though it can be limited by the physical conditions in the soil, and that growth, although dependent upon the weather, is not dependent in the same way and is more directly related to soil fertility.

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A report on the experiments has been submitted to the Meteorological Office, whose requirements largely determined the form the work took, and this report will probably be used by the Meteorological Research Committee in planning future work on evaporation in the British Isles. Even in advance of publication the experimental results have aroused interest: at the John Innes Horticultural Institution Mr. Lawrence has attempted to base an irrigation experiment on them; some of the conclusions have been incorporated into Ministry Bulletin No. 138 on "Irrigation", and advice has been given to the Rother Catchment Board on the irrigation of the Romney Marshes in summer.

The preparation of the report showed some of the points at which increased precision of measurement is desirable. During the period under review apparatus has been designed and set up to give a continuous record of dewpoint: examination of its efficiency is not yet complete.

During the winter of 1945–46 part of the apparatus round the pit was used for an investigation into ice formation below a bituminous carpet, on behalf of the Soil Stabilisation Panel of the Institute of Petroleum. The experiment showed that with a water table at 2 feet below the surface no surface damage resulted, but a water table at 10 in. produced heaving and fracture of the bituminous carpet during frosty periods, due to the accumulation of ice immediately below it. The experiment, apart from its direct result, is of interest in connexion with water movement in soils due to temperature gradients, and the effectiveness of frost action in producing good tilth in autumn-ploughed land.

Observations on slow drainage from soil

In order to determine the amount of water removed from soil by plant roots it is necessary to know how much water has been lost by drainage from the root zone during the same period. Observations during rainless periods in late autumn and early spring, when plant roots are inactive, have shown that the suction continues to rise over a considerable period of time Quantitative interpretation of these results is, however, complicated by the fact that a change in temperature can cause a change in suction.

LABORATORY WORK

Physico-chemical studies on clay

Previous work had shown that a true picture of the electric charges carried by clay particles and their variation with pH cannot be obtained in acid conditions unless great care is taken to remove soluble aluminium by repeated washing. To facilitate this process repeated washing with a solution of acid ammonium oxalate was tried. It was then noticed that under the influence of sunlight this solution is capable of dissolving practically all the iron which gives colour to the Rothamsted subsoil. It was found that the nearly white residue carries substantially all the negative charges detectable in the raw subsoil and that these negative charges do not change in amount with pH within the range 2·5 to 5. Above pH 5 the negative charges increase: this must be due to the dissociation of hydrions. At pH 2 there is evidence of damage to the clay.

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It has further been found that the oxalate-treated clay carries no positive charges that can retain chloride ions. This result shows that in the Rothamsted subsoil the positive charges are not on the surface of the clay mineral proper, but are carried by the material consisting mainly of hydrous ferric oxide which is soluble in acid ammonium oxalate under the influence of sunlight.

Negative adsorption in jute

Very careful measurements have been made of the increase in chloride concentration which occurs when solutions of alkali chlorides are shaken up with dry jute. The results can be expressed as the volume, V, of water apparently taken up per 100 grams of jute. Taking the ideal system consisting of two parallel charged surfaces separated by a film of solution, it can be seen that V should approach a limiting value for very low salt concentration and should be inversely proportional to the square root of the salt concentration at higher concentrations, the proportionality factor giving a measure of the surface area. The cellulosic material, of which jute and similar fibres are built, has a porous structure. From the values of V obtained at pH 1·3 when almost all the carboxyl groups are —COOH groups, it can be seen that about 11 c.c. of water is taken up into pores so fine that chloride ions are excluded (presumably by their size). At pH 6 there is in addition a repulsion of chloride ions by the negatively charged carboxyl groups. V then exceeds the value at pH 1·3 by an amount which follows closely the expected change with salt concentration. It is deduced that there are passages through the fibre substance averaging 5 mμ to 10 mμ in width the total internal surface being 1 to 2 $\times$ 10^8 cm^2., or about 4 acres per 100 grams of dry matter.

Ionic forces in thick films of liquid between charged surfaces

We still know very little about the forces that operate between clay particles through the water films that separate them. A theoretical discussion of the osmotic activity of exchangeable ions in a water film separating two charged surfaces shows that a small repulsive force operates, which varies inversely as the square of the distance separating the surfaces when this is of the order of 100 mμ. The equation obtained also applies to the film held on a single charged surface, and receives considerable support from optical measurements of film thickness made by Deryagin and Kussakov (5). The extension of the theory to thinner films presents considerable difficulties.

Vapour pressure of sugar solutions

The work on the vapour pressure of sugar solutions was continued: following an examination of the published data relating to the isopiestic method of comparing solutions, the work was extended to include glycerol, which it was hoped would prove a suitable standard material for vapour-pressure determinations in general, since glycerol is miscible with water in all proportions and the deviations from ideal behaviour are comparatively small.

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Work of the Physics Department on Natural Evaporation

By H. L. Penman

Introduction: published work up to 1944

Evaporation is a very widespread phenomenon in nature and is largely beyond human control. At one extreme there is large-scale evaporation from the oceans, upon which the supply of rain is dependent; at the other there is small-scale evaporation from plant leaves and other organisms, of importance in micro-climatology. Between the extremes is the broad range of phenomena upon which the return of the rain to the atmosphere depends (1), phenomena of equal interest to the water engineer, the agriculturist and the pedologist. In agriculture, the transpiration of growing crops provides the main evaporation problem, but there is also evaporation from bare soil, regarded favourably when it dries out the land to permit cultivation operations, but too often regarded unfavourably when it is thought to be robbing nearby plants of moisture.

During the past few years the Physics Department has intensified the field studies in evaporation which had their foundation in the work of Dr. Keen over 25 years ago. Experiments were done in cylinders, uncropped, and a study of the retreat of the water table in various soil types, initially saturated, showed that even in the severe drought of 1921 there was little or no water movement from a water table lying at 3 or 4 ft. below the surface of Rothamsted clay soil, and for Woburn sand the limiting depth was about 14 in. (2). These experiments did not show how much water had evaporated from the soil, but, for the local soil, the drain gauges installed by Lawes and Gilbert in 1870 have provided records from which information about amounts and seasonal variation of evaporation from fallow soil could be obtained. The seasonal variation and its dependence on weather factors have become known partly from statistical analyses of the rainfall and drainage records (3, 4, 5), partly from physical reasoning and analysis of the automatic records available since 1925 (6, 7, 8), and partly from laboratory experiments (9). The results have shown that water movement in a soil with only a slight moisture deficit is extremely slow: as the deficit increases, the reluctance to move increases enormously. Drying conditions at the surface of bare soil, initially at field capacity, tend to set up a liquid movement from below to the surface. If the drying rate is small, as it is in winter, the flow of soil water can keep pace with it, so maintaining a steady evaporation rate very nearly equal to that from an open water surface and calculable from weather data. If the drying rate is great, the flow of soil water cannot keep pace with it, and the top layer of soil dries out even though moist soil conditions exist only a few millimetres away. This is characteristic summer behaviour in which the vaporisation takes place some few millimetres below the soil surface: the extra diffusion path thereby imposed reduces evaporation to very small amounts, and the rate ceases to have any dependence on weather factors other than rainfall. Thus, under English summer conditions, bare soil can be regarded as self-mulching, so that surface cultivation other than

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that required for weed killing is a redundant operation as far as moisture conservation is concerned, a conclusion that is in keeping with the Department's findings in cultivation experiments (10).

Recent work: theoretical

The work on bare soil showed the complexity of the problem, but in the later stages there emerged the possibility that an analytical treatment might be successful when the surface was saturated, for a crude aerodynamical estimate of evaporation rates from weather data had been successful in accounting for the observed order of magnitude (6). For a number of reasons it seemed best to apply this analysis to evaporation from an open water surface, and to obtain comparative figures for the ratios of evaporation bare soil/open water and turf/open water under conditions where soil moisture was non-limiting.

Sink strength

Two approaches have been made. In the first, evaporation is regarded as due to a difference in vapour pressure between the evaporating surface and the air above it, the rate of transport depending on the degree of turbulence in the air moving over the surface. Eddies sweeping down onto and across the surface will take up vapour and move away as slightly damper air masses, gradually to mix with their drier surroundings away from the surface. The theory of the process, developed elsewhere (11, 12), leads to the following (simplified) form for the evaporation rate:—

$$E = C\ (e_s - e_d)\ u^{\cdot 76} \qquad (1)$$

where E is the evaporation in unit time, C is a constant involving dimensional and weather factors, e_s and e_d are the water vapour pressures at the evaporating surface and in the air above respectively, and u is the horizontal wind velocity. As the analysis is effectively measuring the ability of the air to take up vapour, i.e. to act as a "sink" for vapour, it is convenient to refer to estimates based on this equation as "sink strength" estimates.

Energy balance

The second approach has been more purely physical. Evaporation is an energy change, and by treating the problem as an example of conservation of energy one might be able to draw up an energy balance sheet leaving evaporation as the only unknown. Little used for land surfaces, as the balance sheet was drawn up it was found to have been extensively used in oceanography (13). During the day, sun and sky light provide a certain measurable amount of energy, of which a small part is reflected and a negligible part used in photosynthesis. Throughout day and night an exchange of long-wave energy takes place between the earth and the water vapour of the atmosphere, partly intercepted by clouds. Precise formulation of this long wave exchange has not yet been achieved (11), but, with this limitation, it is possible to write down an expression for the heat budget (H) of the test surface as a function of incoming sun and sky radiation, mean air temperature, water vapour content of the air and cloudiness. This heat, H, is used up in evaporation, E, in warming the air, K, in warming the evaporating material, S, and in warming the surround of the material, C. Under

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certain conditions S and C can be ignored: an approximate expression for the ratio of K/E is available (14), and as this ratio is rarely very great it is possible to deduce E from H.

Recent work: experimental

Experiments to test these two approaches were begun in 1944 using the twelve cylinders which Dr. Keen had set up in 1924 round a pit in the meteorological enclosure. Five had been filled with Woburn soil and in 20 years had settled to a near natural state. Each of these five was joined to an empty cylinder at the bottom, so making a set of five U-tubes. Waterproof covers were provided for the empty cylinders, and on two of the soil cylinders turf was laid in the spring of 1944. One of the remaining empty pair was filled to the brim and used as an open water surface. Water was run into the empty arms of the U-tubes until they were brimful and water was standing on the soil surfaces: it was then run out until the water levels had reached pre-determined depths. These were 16 in. below bare and turfed surfaces, 10 in. below bare and turfed surfaces and 5 in. below the remaining bare surface. From the daily measured movements of the water table it was possible to estimate evaporation and transpiration, and contemporary records were taken of surface, air and dew-point temperatures, wind speed, solar radiation, and cloudiness.

Results: open water

The results have not confirmed the expectation based on the sink strength formula. It has been found that the daily evaporation rate from open water is governed by:—

$$E = 0{\cdot}35(1 + 9{\cdot}8 \times 10^{-3} u_2)(e_s - e_d) \text{ mm./day} \qquad (2)$$

where u_2 is the wind velocity in miles/day, and e_s and e_d are in millimetres of mercury. This result, which differs insignificantly from that obtained in a very comprehensive American investigation (15), differs from the formal analysis on the fundamental issue of the value of the evaporation rate at zero wind velocity. The overall mean value of observed evaporation is about two-thirds of the value that would be obtained from eq. 1 for an average wind speed.

The energy balance has been successful for periods of several days in length and has often been successful for single days. A comparison of the two approaches is given in the table below. This gives the run-of-the-wind, the value of H and the observed open water evaporation for a few days in 1945, with two estimates of evaporation alongside. The first of these has been obtained from the energy balance: the second has been obtained from eq. 2, i.e. from a fitted equation.

Observed and Estimated Evaporation: Open Water

Date 1945	u_2 m.p.d.	H (mm./day)	Evaporation (mm./day) Estimated Energy Balance	Estimated Sink Strength	Observed
June					
11	149	3·64	2·6	2·4	2·3
22	92	5·58	5·4	4·2	4·7
July					
1	197	5·01	4·3	4·7	3·2
12	50	5·80	5·0	3·1	3·6
23	128	5·76	4·7	5·7	4·8
Aug.					
3	67	4·11	3·6	4·3	3·6
17	122	3·76	4·0	2·8	2·8
26	63	3·90	3·4	3·4	3·6
Sept.					
8	128	1·53	1·3	1·4	1·8
14	133	1·36	1·4	0·9	1·1
27	146	1·63	2·0	2·3	1·7

Over extended periods the agreements are better, and applications to other data have shown that the residual empirical elements in both approaches are not purely local in their significance.

Results: bare soil

Results for bare soil have been in keeping with those of earlier work. With the water table at 5 in. below the surface the soil remained moist at all times, and the evaporation rate was about 90 per cent. of that from the open water surface in all seasons. At the next depth (10 in.) the behaviour was much the same except in extended periods of hot weather, when slight surface drying occurred, increasing in area during the day and partially recovering during the night. An appreciable decrease in evaporation rate occurred under these conditions. The transition was complete at 16 in. depth. Within two days of rain the surface dried and evaporation fell to negligible amounts: indeed, it was so slight that it was possible to detect movements of the water table due to other physical causes. It is apparent that between 10 and 16 in. under this sandy soil there is a limiting depth from below which upward movement of soil water cannot take place, a result found previously in another way by Dr. Keen.

Results: turf

In 1945 the water table held at 10 in. under turf was lowered to 24 in., so that, over the two years, data are available for water tables at 10, 16 and 24 in. There were no great differences in behaviour, the transpirations and crop yields being very nearly independent of depth of water table. Over a whole year the transpiration from the well watered turf was about three-quarters of the open water evaporation, with a summer maximum of four-fifths and a winter minimum of three-fifths. The crop used only about one half per cent. of incoming short wave energy for building up plant material. During 1946 a third turf surface was used,

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plentifully fertilized. Summer transpiration from the three surfaces was the same for all, but the newer turf gave a crop yield of more than double that from either of the older surfaces, again about equal. It appears that where there is a plentiful supply of water the crop behaves rather like a piece of wet blotting paper and its consumption of water is forced at one end by sunshine, wind, humidity and temperature: under drier conditions it may be restricted at the other by the inability of the roots to find sufficient water in the soil to keep pace with this external forcing. Although plant growth is also dependent upon weather conditions it is not dependent in the same way, and is more closely linked to nutrient supply and soil conditions.

Application of the results of this work to catchment areas has shown that annual run-off can be estimated from weather data and, in a similar way, specification of times and amounts of necessary irrigation are possible for intensively grown crops.

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DEPARTMENT OF CHEMISTRY

By E. M. CROWTHER

Several series of investigations involving related work in field, pot and laboratory experiments were continued. Many of these form parts of long-term enquiries under the aegis of committees or conferences of various Government Departments.

THE MANURING OF SUGAR BEET (Ministry of Agriculture Committee on Sugar Beet Research and Education)

This series has continued on comparable lines since 1933. The main set of experiments tests N, P, K, Na and B fertilisers on some twenty commercial farms annually, there being at least one in each of the sugar-beet factory areas. A supplementary series started in 1945 tested nitrate of soda against sulphate of ammonia both in the presence and absence of salt. The results in the first two seasons brought out a definite superiority of nitrate of soda over sulphate of ammonia. This could be ascribed in part to the nutrient value of the sodium, but there was also evidence that nitrate was better than ammonia as a source of available nitrogen, since sodium nitrate gave better results than the mixture of sulphate of ammonia and salt supplying equal amounts of sodium and nitrogen. Where nitrate of soda was used there was little or no further benefit from supplying additional sodium as agricultural salt. So far no clear evidence of improvement in sugar-beet yields by applying borax has been found in over 60 trials on representative soils, but boron effects are known to be markedly seasonal and the work will be continued to provide the opportunity for proper tests when weather conditions aggravate the effects of boron deficiency.

THE MANURING OF PEAS (Agricultural Improvement Council)

There is a singular lack of experimental evidence about the manurial requirements of peas and beans. Field experiments on beans have been in progress at Rothamsted for several years, and in 1946 a preliminary series of experiments on peas was designed in association with Mr. Shorrock of the Home Grown Threshed Peas Joint Committee and local agricultural officers. The experiments achieved a satisfactory standard of precision. Out of four experiments yields were significantly increased by phosphate in one and by potash in two experiments, but nitrogen, phosphate and potash fertilisers each caused one significant depression in yield. This preliminary series of experiments in which depressions were as frequent as responses suggests that current practice in the manuring of peas rests on an insecure basis. The manurial and cultural problems of any rapidly expanding crop need to be examined systematically by field experiments along lines similar to those employed since 1933 for sugar beet.

BULKY ORGANIC MANURES (Agricultural Research Council)

A series of field experiments at Rothamsted, Woburn and many commercial farms was continued to test a variety of bulky organic manures. The experiments were designed so as to bring out both the nutrient and the physical effects of the manures. The principal

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materials tested were farmyard manures, sewage sludges, bracken, composts of straw with either sewage sludge or fertilisers, and straw ploughed in directly. Particular attention was given to experiments on horticultural crops and especially to keeping the experiments going over several seasons. In this way evidence has been obtained of physical effects of organic manures in the second or third season of experiments which had shown no such effect in the first year.

The residual manurial values of fertilisers and the manurial value of feeding stuffs

The Director and Dr. Crowther served on a Conference constituted by the Ministry of Agriculture to revise the Voelcker and Hall Tables of residual manurial values. For the first time since this subject was raised by Sir John Lawes in 1870 it was possible to obtain an agreed report acceptable to the interested parties. The Report was published in the Ministry's Journal. The scientific background, including the results of Rothamsted and Woburn residual value experiments, has been summarised (17) in a paper, and the immediate practical problems considered in two lectures (14, 15) to the Central Association of Agricultural Valuers.

Forest nurseries (Forestry Commission Committee on Nutrition Problems in Forest Nurseries)

The new programme of forest planting requires a rapid increase in the production of seedlings and transplants, especially of Sitka Spruce, Scots Pine and other conifers, but many acute problems remain to be solved in nursery practice. Sitka Spruce in particular grows very poorly in many nurseries. A series of manurial experiments was therefore started in 1945 to test fertilisers and composts, alone and in combination, on a range of nurseries, including an established nursery and new ones on old arable land, cleared forest, and cleared heathland. The preliminary results showed that on the sites known by their conditions and by soil analyses to be acutely deficient in nitrogen, phosphate and potash the seedlings and transplants responded strikingly to additions of these plant foods in suitable forms. The effects of various composts could be largely interpreted in terms of their contents of the three major plant foods. On the very poor soil of Wareham Heath there were particularly large responses to each of the elements nitrogen, phosphorus and potassium. Growth was unsatisfactory and visual symptoms of acute nutrient deficiencies were striking where only two of these three elements were added. Some of the past prejudice against the use of fertilisers in forest nurseries on such soils may well have been due to the aggravated symptoms of one nutrient deficiency produced by making good definciencies in one or two other plant foods. With all three nutrients supplied as fertilisers large vigorous and well-furnished seedlings and transplants were produced in 1946 on what was intrinsically an extremely poor soil.

Some of the experiments were necessarily of complex statistical design because it was necessary to test different amounts and forms of each of the three major elements. Some of the differences between alternative forms of fertiliser have already been demonstrated. In an established nursery at Oxford it was shown that

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the growth of Sitka Spruce could be greatly improved by acidifying the slightly calcareous soil on which this species has consistently failed for a number of years.

Plants from many of the experimental treatments in several nurseries will be planted out in experiments in three forests in 1947 and manurial experiments will also be made in these forests.

This work must be continued over a number of seasons and a variety of soils before a sound manurial policy for forest nurseries can be established. The results of the first two seasons are promising. Apart from their potential value for forestry practice they provide interesting material for studying problems of plant nutrition and soil chemistry at much lower levels of fertility than are obtained with agricultural crops.

FERTILISER PLACEMENT (Agricultural Research Council)

Experiments on potatoes in 1945 showed no differences between alternative methods of applying fertilisers. Through experience gained in the field in 1945 it was possible to suggest a number of improvements in the experimental drill built for this work by the National Institute for Agricultural Engineering (12). An improved drill was used in 1946 in 16 experiments on potatoes in the principal potato-growing areas of south and east England. The methods of fertiliser applications tested were, broadcasting before ridging, broadcasting after ridging, placement in contact with the seed and placement in two sidebands below seed level. There was very little difference in crop yield between broadcasting over ridges and placement in contact with the seed or in sidebands. The normal method of broadcasting over ridged land brings the fertiliser close to the sets and ensures the merits of controlled placement. Nothing is gained by any more elaborate method of applying the fertiliser. This result is at variance with the American experience that banded placement below and to the side of the sets is preferable. The explanation of the discrepancy is no doubt due to the common practice in America of using cut sets which are planted together with fertiliser by machines working on the plot. Broadcasting before ridging was clearly inefficient. Three parts of fertiliser applied before ridging gave about the same yields as two parts of fertiliser applied in any one of the three methods after ridging.

As the result of discussions during 1946 a new experimental drill for fertiliser placement tests on small seeds is being built by the National Institute of Agricultural Engineering. It is hoped to be able to use this in 1947.

PHOSPHATE FERTILISERS (Ministry of Supply)

Field experiments, mainly in collaboration with Advisory Chemists, were laid down to test a variety of forms of phosphate fertilisers, new and old. Yields were obtained from 29 experiments in 1945 and from about 25 in 1946. In the latter year the new fertiliser, silico phosphate, from the Ministry of Supply Experimental Plant at Strood was tested on a variety of soils and crops with promising results (13). Special attention was also given to dicalcium phosphate, both as a more or less pure commercial material and as a major ingredient of mixtures of superphosphate with basic materials. The fuller investigation of dicalcium phos-

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phate is of great theoretical and practical importance. It may be possible in some soils to cut down the wastage of phosphate by rapid fixation. If it can be shown that a phosphate insoluble in water may be almost as active as superphosphate under appropriate conditions there will be good grounds for reviewing the whole position of the water-solubility test in the Regulations of the Fertiliser and Feeding Stuffs Act. At present many promising developments in the production and use of fertilisers are prevented by the commercial and legal customs of treating water-soluble phosphoric acid as having unique merit. This test, originally proposed by Sir John Lawes merely to distinguish between good and bad superphosphate, has outlived its usefulness and is now a serious obstacle to technical progress in many branches of science and technology.

Basic calcium phosphates

All consideration of the reactions and behaviour of phosphates in soils and fertilisers are rendered difficult by the lack of precise data on the equilibria and reactions between lime and phosphoric acid in aqueous systems. Equilibria are difficult to establish and the reactions are complicated by the low solubility, the ease of hydrolysis and the absorptive powers of the solid phases. As an index of the uncertainties it may be stated that there is still considerable doubt as to whether any such material as "tricalcium phosphate" can exist in contact with water, and yet the name and formula of this substance are used in almost all text books and discussions on soils, fertilisers and animal physiology. Until 1926 this hypothetical substance also served in expressing all phosphate analyses under the Fertiliser and Feeding Stuffs Act.

In re-examining the reaction between phosphoric acid and calcium hydroxide solutions evidence was obtained to suggest that some of the anomalies may be explained by the special properties of dicalcium phosphate, which may occur in some of the more alkaline as well as the more acid systems. A Russian method of precipitating basic calcium phosphates by very slow reactions in large volumes of water was found to give promising results.

With the object of finding a more adequate method of characterising available phosphates in fertilisers, studies have been commenced on the calcium citrate system and on the reaction between calcium phosphates and fluorides during extraction processes.

Soil organic matter

In collaboration with the Biochemical Department an investigation is being carried out on certain aspects of soil organic matter. The usual methods of extraction with strongly alkaline solutions may produce artefacts and a search is being made for milder reagents. This led to the consideration of organo-metallic complexes in soil (21), and to a study of autoxidation of soil organic matter in alkaline solution.

Chromatographic analysis gave little success with the "humic acid" complex, but a useful resolution of the so-called "fulvic acid" fraction was achieved by using charcoal.

Some results suggest that mucopolysaccharides or mucoproteins

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may be present in soil organic matter, but quantitative estimation of these materials and related chemical groups still present great difficulties. Thus no reliable method has yet been found for estimating uronides in soil.

Iron in soils

Several methods of extracting iron from soils and soil colloids were studied with the object of finding better methods for characterising the forms of iron in soils and for studying the movement and deposition of iron compounds in soil formation. The work included a study of stability of iron-humus sols and the properties of complexes of iron and organic acids.

Manganese and other minor elements

In collaboration with the Biochemical Department work was continued on the nature of the so-called "readily reducible" manganese of soils (22). It was found that polycarboxylic and hydroxyacids but not non-substituted acids formed complexes with manganic manganese which are soluble over a wide pH range. Extractants, such as pyrophosphate, polycarboxylic or hydroxy-acids which dissolve polyvalent cations (e.g. manganese, iron and copper) from soil also extract organic matter (27). It was found that organic soils yielded more manganese in alkaline extracts than in neutral ones, and also that this manganese was present in the divalent form (26). Preliminary pot experiments were carried out to test the availability of manganic manganese. A fresh raw sphagnum peat, capable of fixing large amounts of added copper in a form which was soluble in pyrophosphate but not in the salt solutions used to determine "exchangeable" bases, also caused iron and copper chlorosis in oats.

Spectrographic analyses

Sugar beet tops and roots from the standard series of fertiliser trials in 1945 were analysed for many elements, including boron. Many analyses were also made on samples of sugar beet taken in joint work with Mrs. Watson of the Plant Pathology Department and Dr. Hull of the Midland Agricultural College (24). Some of these experiments brought out interesting interactions in plant composition. Thus in one experiment addition of salt greatly reduced the calcium and magnesium contents, and nitrogen greatly increased the manganese contents of the leaves. Manganese sulphate applied ten weeks after sowing was far more effective in raising the manganese contents of the leaves than that applied at sowing.

A paper has been prepared for publication on the mineral composition of oil palms in Nigeria showing various deficiency symptoms and other pathological conditions. Analyses were also made on cotton leaves from South Africa and Sitka Spruce plants from the forest nursery investigations already mentioned.

In a survey of manganese-deficient soils in Hertfordshire in 1945 many samples of cereals and weeds were collected and analysed. Where oats were showing symptoms of manganese deficiency and wheat was free, the wheat nevertheless had lower manganese concentrations in its leaves. Vetches and cleavers both had higher concentrations than the two cereals. It was also found

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in this survey that chickweed belonged to the "high-sodium" class of plants, with 2·0 per cent. of Na_2O on the dry matter as compared with less than 0·1 per cent. for many other species.

Spectrographic methods for boron and nickel were developed.

Dr. J. B. Hale worked for six months in 1946 with Professor Lundegardh at Uppsala and Professor Goldschmidt of Oslo.

An investigation on the mineral composition of Broadbalk straws over a term of years was completed. The results were examined in relation to manurial treatments and weather conditions. A number of the analytical data were found to be significantly related to the distribution of rain, when examined by Fisher's method of analysis.

Rothamsted classical plots

Steady progress has been made in preparing for analysis the large mass of soil samples taken from Broadbalk in 1945. A similar set was taken from Hoosfield in 1946. Preliminary work has been done in building up apparatus and checking appropriate methods for the critical analyses required in analysing these soil samples.

Analytical and other methods of investigation

Work on rapid and micro-methods of analysis of soil and plants has been continued by several members of the staff. By using a mixture of selenium, copper sulphate and a large amount of potassium sulphate and digesting for one hour the recovery of nitrogen from guanidine was raised to 99 per cent. The micro-Kjeldahl method was developed to deal with from 20 to 30 mg. of dried ground plant material. It was found that the needles of Sitka seedlings have much the same nitrogen, phosphorus and potassium content as the average of the whole plant. It may therefore become possible in future work to judge the nitrogen status of experimental plants by needle samples which are easily collected and analysed.

It was found that moderate amounts of nitrate could be included in the total nitrogen by both micro- and macro-Kjeldahl analyses with salicylic acid even in the presence of appreciable amounts of water.

In extending an earlier method of examining bulky organic manures by measuring the production of carbon dioxide under standard conditions, it was found possible to reduce the labour involved in ensuring good aeration, by designing an apparatus in which hydrogen peroxide automatically supplied additional oxygen as required.

The Ter Meulen-Spithost method for organic carbon in soils has been modified to a compact unit with volumetric determination of the carbon dioxide.

Apparatus

Mr. Nixon and Dr. Lees of the Biochemistry Department have designed and constructed a simple and robust pH meter which incorporates all the normal features of commercially made instruments but has the additional advantages of being driven entirely

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from dry batteries and of being ready for use a few seconds after switching on. Work has been started on the design of a different type of direct reading pH meter which will be accurate to 0·1 pH and sufficiently stable, light and robust to be used in the field for survey and advisory work or in the laboratory where the more refined instrument is not required.

Technique for grassland experiments

In collaboration with the Statistics Department some 800 samples of pasture grass were taken in 1946 from random points in the High Field Experiment at Rothamsted and in a trial at Biggleswade. Similar samples from High Field in 1945 were bulked and analysed. The purpose of the work is to discover a suitable technique for grassland experiments, especially on the relative production of leys and permanent grass. The High Field experiment provides the opportunity of comparing the starch and protein equivalents of the herbage on a number of plots with the actual live weight increases of the grazing animals.

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DEPARTMENT OF SOIL MICROBIOLOGY

By H. G. THORNTON

The following main lines of research were carried out during the year:—

A. WORK DEALING WITH THE SOIL MICROPOPULATION

1. *Direct examination of organisms in soil*

Estimates of the total numbers of bacteria in soil cannot be obtained from plate counts owing first, to the uncertainty as to whether colonies are developed from single cells or from clumps of bacteria in the soil suspension, and secondly, to the fact that no single nutrient medium will support the growth of all soil bacteria. Total estimates can only be made by the direct counting of bacteria in stained films of soil. A difficulty in preparing such films has been the disturbance of the soil suspension due to surface tension forces during drying, which resulted in an uneven distribution of microorganisms over the dried film. If, however, melted agar be used as a diluent, gelation of the suspension preserves the original distribution of the soil particles and organisms. Moreover such films can be made of known thickness by setting the suspension in a haemocytometer so that the volume of suspension in a measured area of film is readily calculated. The details of the method finally developed by P. T. C. Jones and Janet Mollison are as follows:—

A known quantity of soil is added to 5 c.c. of sterile distilled water and ground in a small sterile crucible. The resulting suspension is poured into a sterile flask. The soil remaining in the crucible is washed in a further 5 c.c. distilled water and the suspended matter added to the flask. The soil suspension is made up to 50 c.c. with melted 1·5 per cent. agar previously filtered and sterilised. The suspension in the flask is well shaken and a drop is placed on a haemocytometer slide of 0·1 mm. depth, immediately covered by a coverslip and allowed to set. The coverslip can be removed under distilled water and the film gently floated on to a microscope slide and allowed to dry. The dried films are then stained for one hour in the following solution:—

Phenol (5 per cent. aqueous)	15 c.c.
Aniline Blue (water-soluble) (1 per cent. aqueous)	1 c.c.
Glacial acetic acid	4 c.c.

(This mixture must be filtered about an hour after preparation.)

The films are washed in 95 per cent. alcohol, dehydrated in absolute alcohol and mounted in Euparal. Counts of microorganisms are made in 20 random microscope fields on each of 4 replicate slides. Since the volume of 20 fields is known the number of organisms per gram of soil is readily obtained. For observation with an oil immersion it has been found that a suitable density of soil suspension is obtained by taking an initial quantity of soil such that 0·00000005 gram are contained in the volume represented by 20 microscope fields.

Statistical analysis of bacterial counts from replicate fields shows that the method gives a valid estimate of the soil microflora.

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Recovery counts of bacterial suspensions added to sterilised soil have given 93 to 98 per cent. recovery. Total numbers of bacterial cells found in natural soils have ranged from 3,000 million to 8,000 million per gram. The method can be adapted to give counts of fragments of fungus mycelium in soil.

2. *Classification of soil bacteria into nutritional groups*

Following the line of work developed by Lochhead in Canada, Mr. A. V. Garcia has studied the bacteria and proactinomycetes that formed colonies on platings from the three plots of Barnfield receiving (Plot 8, O) no manure, (Plot 1, O) farmyard manure, and (Plot 4, A) complete minerals and ammonium sulphate.

Plate counts made from samples taken on eight occasions covering a period from April till November, using several different agar media, invariably gave the highest counts from the farmyard manure plot and the lowest from the unmanured plot. The organisms that grew on platings were classified according to their growth requirements. The soil from the farmyard manure plot was characterised by an especially large percentage of bacteria that require yeast for their growth. The plot with mineral manurng contained a majority of bacteria that could grow on simple media without growth substances.

These studies on the bacteria from the three plots were accompanied by counts of amoebae carried out by Mr. A. V. Garcia and Dr. B. N. Singh.

3. *Microbial decomposition of resinous substances in soil*

Mr. P. C. T. Jones has continued this investigation, carried out at the request of the Road Research Board (D.S.I.R.) and having the practical object of stabilising resins that are added to soil in order to produce a temporary road base resistant to water absorbtion. A number of bacteria and fungi capable of attacking such resins were isolated from soil and classified according to their morphology and biochemical reactions. The breakdown of compacted blocks of soil was found to be correlated with the increase in numbers of such organisms in the blocks. The effects of various antiseptics on the organisms were studied.

4. *Nitrifying bacteria*

Dr. Jane Meiklejohn has commenced work on nitrigying bacteria. The object of the work is to discover what organisms are mainly responsible for nitrification in Rothamsted soils and what effect organic substances have on this process.

5. *Soil actinomycetes*

Mrs. Dagny Oxford's work on this group has been mainly concerned with the investigation of two problems, (1) the factors which affect the development of aerial mycelium and determine the morphology of actinomycetes in soil, in which the type of growth is generally quite uncharacteristic of their species, (2) the lipoid nature of the outer wall of the aerial mycelium and of the spores. The difficulty in wetting the spores, due to this, makes it very difficult to obtain a spore suspension and hence affects the value of actinomycete colony counts obtained from a suspension of soil.

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6. *Mycorrhiza*

Dr. Janet Mollison has surveyed the occurrence of mycorrhizal fungi in clover and in wheat. They were found almost universally in clover and seasonally in wheat. Their importance to the plant has not so far been ascertained since attempts to isolate the fungus in pure culture have not yet succeeded.

7. *Myxobacteria*

Considerable advance in the study of soil myxobacteria has been made during the year by Dr. B. N. Singh whose work is described more fully below and by Dr. R. Y. Stanier who investigated a group of these organisms found to attack chitin.

8. *Conditions influencing the excystation of amoebae*

Miss Lettice Crump has found that the type of bacterial food supplied to soil amoebae influences not only their reproductive rate but also their excystation. This discovery may explain the rapid changes in the proportion of cysts to active forms previously found in soil.

B. Work dealing with the nodule bacteria (*Rhizobium*) of leguminous plants

9. *Dissociation produced in Rhizobium by bacteriophage*

Dr. Janina Kleczkowska studied the influence of bacteriophage on the strain called F12, a "variant", ineffective in fixing nitrogen in the clover plant, which was derived from the effective strain A. Treatment with bacteriophage usually gives rise to the appearance of 'phage resistant variants which also differ from the susceptible parent strain in other characters such as colony appearance and more rarely in behaviour towards the host plant. Fifty variants of F12 obtained by 'phage treatment were tested on the clover plant. Of these one was consistently effective, three were consistently intermediate in nitrogen fication, three others gave inconsistent results on replicate plants and 43 strains remained ineffective. These characters were maintained after several passages through the plant. Similar treatment of the ineffective strain C with bacteriophage produced a variant giving effective and ineffective responses on different replicate plants.

10. *Geographical strains of clover nodule bacteria*

The testing of samples and classification of results continued during this season.

Further tests were also made of the effect of season on nitrogen fixation in continuation of last year's work.

11. *Competition between strains of nodule bacteria*

Mr. S. Bhaduri continued the study of competition between two strains of *Rhizobium*. There is evidence that this is acute between certain strains but not others. No evidence of competition between *Rhizobia* from different "inoculation groups" could be found.

12. *The interaction of the clover plant with Rhizobium*

Dr. P. S. Nutman continued investigations along the following lines:—

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(a) *Genetics of the clover plant*

Confirmation was obtained of the work suggesting that resistance to infection in clover was due to the interaction of a recessive gene with a maternally inherited factor. The inheritance of the effectivity response as regards nitrogen fixation appears to be of two kinds (1) a polygenetic inheritance that is apparently not specific to a given bacterial strain and (2) a single gene effect that is highly specific to the bacterial strain concerned. The behaviour of one of these single genes has been exhaustively studied and those of four others have been incompletely investigated. The results suggest that the genes concerned may be allelomorphic.

(b) *Physiological studies*

These have been concerned, first, with the physiologically homologous nature of lateral roots and nodules and, secondly, with the partial inhibition of nodule formation on plants growing in association. A paper on the first of these investigations is being prepared.

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Micro-organisms Capable of the Selective Destruction of Soil Bacteria

By H. G. Thornton

Introduction

The maintenance of satisfactory biochemical activity in a field soil depends on the establishment in it of a population of those types of micro-organisms that produce desirable chemical changes therein. This will be brought about only if the soil environment is suitable. An important factor in this environment is the existence and activity of other micro-organisms that limit the numbers of useful organisms either by competing with them for nutrients, by harmfully changing the chemical environment (as by producing toxic secretions), or by directly eating them. The competition between related strains of nodule bacteria (*Rhizobium*) studied in this department appears to be an example of the first type. The production of antibiotic secretions by fungi and actinomycetes, many of them derived from soil, has been much studied elsewhere and has given rise to a vast literature. Their production by certain of the Myxobacteria, however, has received little previous attention. Some recent investigations in this field are summarised below. There is in soil a considerable and active population of protozoa and related organisms that feed directly on bacteria. This group has been the subject of investigation at Rothamsted for many years.

In the years between 1919 to 1939 the General Microbiology Department carried out many investigations concerning the protozoan fauna of soil whose object was to elucidate the ecological importance of protozoa in soil and particularly their effect on the

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bacterial population. A systematic survey of the types of protozoa in soils was carried out and a method was developed for the approximate enumeration of protozoa in soil samples (1, 13). With the help of this technique it was shown that the numbers of active amoebae and of flagellates in field soil underwent rapid fluctuations and that the rise and fall in numbers of active amoebae found in daily samplings was on the whole inversely related to that of bacterial numbers found in plate counts (3). Experiments also showed that the presence of amoebae kept down the numbers of bacteria in soil stored in the laboratory (2), so that it seemed reasonable to suppose that they control the size of the fluctuating bacterial population in the field. Laboratory experiments with pure bacterial cultures with and without the addition of protozoa showed, however, that the latter do not always depress the biochemical activity of the bacteria. They may stimulate this activity by keeping the bacteria at a lower numerical level than they would attain in pure cultures. This probably results in the culture remaining in a younger and more active condition (4, 5, 8, 9, 11).

The differential feeding of soil protozoa

It is an interesting question as to how far protozoa are selective in consuming certain species of bacteria and not others. There was some previous work suggesting selective feeding, but the question had been little studied.

To investigate this problem B. N. Singh developed an elegant method in which amoebae could be given a choice of bacterial food supplied as streaks, each of a different bacterial species, disposed in a petri dish in star formation at the centre of which the inoculum of amoebae was applied. Bacteria could be classified into (1) species readily eaten (2) those that were slowly eaten but eventually completely consumed (3) those that were only partly consumed and finally (4) an entirely inedible group (14). No correlation could be found between edibility of bacteria and their gram staining reaction (14, 17), but nearly all pigmented organisms other than yellow and orange were inedible. It is thus possible that certain bacterial pigments afford an advantageous protection against amoebal attack (16, 17). In other cases the edibility or otherwise of a bacterium seems to be determined by a fine difference not readily identified, since strains of Aerobacter similar in morphology and physiology differ in edibility (14). This is also the case with strains of *Rhizobium* (16).

Species of soil amoeba differ somewhat in their preference as regards bacterial food both amongst themselves and from the soil flagellate Cercomonas which also feeds selectively. Amoebae grown on plates or in sterilised soil culture can select edible from inedible bacterial food where both are supplied and, in soil they greatly reduce the numbers of edible bacteria (14). This discovery suggests that they are able in field soil to alter the quality of the bacterial flora as well as limiting its total numbers. It seems likely that this is their more important function.

Bacteria that are inedible to amoebae include certain types whose mere presence whether alone or in mixture with edible forms is definitely toxic to the amoebae. These toxic types include

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pigmented forms and there is evidence in some cases that the pigment itself is toxic. This is so in the case of the soluble pigment excreted by *Pseudomonas pyocyanea* and in that of *Chromobacterium violaceum* and *Serratia marcescens* whose violet and red pigments are relatively very insoluble in water (17). It seems possible that the further study of bacterial pigments toxic to protozoa may lead to the discovery of substances of importance in the treatment of protozoal diseases.

The estimation of numbers of protozoa in soil samples

This work on the differential feeding of soil protozoa revealed a serious defect in the previous method used for estimating protozoal numbers in soil and made possible the development of an improved method giving valid estimates. The numbers of protozoa in soil are too small to enable them to be counted directly in stained films of soil nor will they form colonies on platings. The methods used are therefore based on observing their presence or absence in a range of soil dilutions. In the methods previously used, a range of dilutions of the soil sample were made and duplicate plates of nutrient agar were inoculated with 1 c.c. portions of each dilution. From the presence or absence of protozoa at each dilution the numbers were estimated, using the Table worked out by Fisher and Yates (6). In this technique the mixed bacteria added with the diluted soil suspension were relied upon to supply food to any protozoa that might be present at that dilution. The selectivity of protozoal feeding habits shows that this method may give invalid results because an individual protozoan may come to lie on the plate amid inedible or even toxic bacteria and thus fail to grow. Apart from this serious defect the previous method was greatly limited in accuracy by the small replication enforced by the use of an entire petri dish for each culture. In his study of bacterial food supply Singh found that a number of bacterial species were readily eaten by all protozoa tested. Thus by applying the diluted soil suspension to a pure culture of such a bacterium placed on the surface of agar without any added nutrients, growth of inedible bacteria from the suspension was checked and a suitable food supply to any protozoa that might be present was assured. Replication of cultures at each dilution was obtained by the use of 8 glass cells per petri dish in each of which a replicate culture was set up (19, 20). Extensive tests have shown the method to give a reliable estimate of the numbers of amoebae and flagellates in soil samples although recovery tests with amoebae show that the estimates are consistently low owing to about 20 per cent. of the amoebae lacking viability. This method has been applied by Singh and Garcia to samples taken from three plots of Barnfield.

The occurrence and distribution of giant Rhizopods in soils

The use of plain (non-nutrient) agar with a pure bacterial culture as food supply has proved an excellent method for the culture and isolation from soil of several groups of soil organisms that derive their food from bacteria but which have until now been considered rare in soil. Amongst these are the giant amoeboid organisms of the genus *Leptomyxa* described by Goodey (7) but not since studied. By using his method of isolation B. N. Singh has

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found these organisms to be common and widely distributed in soils. They have been found in all of 26 arable and in 12 out of 33 grassland soil samples collected from 10 counties in Great Britain. They occur in variously manured plots from Barnfield and Broadbalk. Approximate estimates give their numbers as of the order of 1,000 per gram. Since they have an individual volume about 1,000 times that of a typical soil amoeba the numbers of bacteria that they must consume to maintain their numbers are likely to be considerable. They resemble amoebae in being specific in their food requirements. Their life cycle and ecology are under investigation.

Acrasieae

A second group of microorganisms, whose presence as regular soil inhabitants has been revealed by the technique of isolations using pure bacterial cultures as food supply, is the Acrasieae. These organisms were formerly believed to be derived from dung, but a number of strains of the genus *Dictyostelium* developed from dilutions of soil added to non-nutrient agar smeared with bacteria edible to protozoa. B. N. Singh has obtained them from 33 out of 38 arable and from 3 out of 29 samples of grassland soils obtained from localities ranging over 10 counties in Great Britain. They occur in all of the variously manured plots of Barnfield and Broadbalk, most of which receive no dung; they are hence true soil inhabitants. The Acrasieae have a life cycle comprising an amoeba-like stage which forms a "pseudoplasmodium" developing into mucor-like fruiting bodies inside which spores are formed. The myxamoebae resemble true amoebae in being differential in their feeding habits although in some cases different species of bacteria are eaten by myxamoebae and true amoebae respectively. The type of bacterial food greatly affects the morphology and occasionally the colour of the fruiting body formed. On some species of bacteria very abnormal fruiting bodies are formed so that the existing classification of the Acrasieae, based on the morphology and colour of the fruiting body, is only applicable where due regard has been taken to the food supply and cultural conditions. When added to sterilised soil supplied with a suitable bacterial culture, Acrasieae can spread through the soil at an approximate rate of 1 in. in 24 hours and will multiply therein, ultimately producing fruiting bodies on the surface. They greatly reduce the bacterial numbers in the soil culture. There is also evidence that they can multiply in fresh unsterilised soil. It thus seems likely that they are a factor affecting the bacterial population in arable soils (18, 22, 23).

Myxobacteria

Methods similar to those used in isolating giant Rhizopods and Acrasieae have revealed the presence in soils of appreciable numbers of the "higher" types of Myxobacteria of the genera *Myxococcus*, *Chondrococcus* and *Archangium* (21). They have been found in all of the 38 samples of arable and in 21 out of 31 samples of grassland soils collected over the counties of Great Britain. Their occurrence in all the classical plots of Barnfield and Broadbalk again shows them to be true soil inhabitants and not dung organisms as was

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previously supposed. Counts show that the Barnfield farmyard manured plot contains numbers varying from 2,000 to 76,000 per gram. They are also found in large numbers in compost heaps. The higher Myxobacteria feed on true bacteria by the production of secretions that kill and lyse the latter. Dr Singh and Dr. A. E. Oxford, working in collaboration, found that *Myxococcus virescens*, growing on a cell-free medium, produces two substances, an antibiotic agent that acts most powerfully against gram positive bacteria and a bacteriolytic substance which is a proteolytic enzyme and which lyses dead bacteria. It acts most powerfully against gram negative organisms. A further study of the production and activity of these substances may throw much light on the mechanism of antibiotic activity in general.

Number of bacterial species in soil liable to attack

In assuming the ecological importance in soil of holozoic predators and of organisms producing antibiotic secretions, it is important to form some idea of how many of the numerous and widely different species of soil bacteria are susceptible to attack by one or more of these organisms. Dr. Singh has tested the susceptibility of 84 strains of bacteria nearly all from soil, to attack by five holozoic organisms and to three species of Myxobacteria. The same bacterial strains were used in each test and these comprised a wide range of types differing in morphology, growth habit, gram staining and pigment production and included both common species and others relatively rare in soil. He found that any one species of organism could attack about half of the bacterial species tested, the actual percentages being as follows:—

	Percentages of bacterial strains attacked
Large Amoeba	54·8
Small Amoeba	60·7
Leptomyxa	41·7
Dictyostelium giganteum	57·1
D. mucoroides	61·9
Myxococcus virescens	69·0
M. fulvus	53·6
Chondrococcus exiguus	47·4

But the organisms differ markedly in which particular bacterial strains that they attack. On an average the members of any pair of organisms differ in their reaction to 36 per cent. of the bacterial strains tested. As a result of this specificty in attack all but 6 out of the 84 bacterial strains were attacked by at least one of the 8 organisms although only 6 were attacked by all of them.

This test did not cover the fungi or the numerous actinomycetes in soil that produce antibiotic secretions active against gram positive bacteria. It seems likely that very few species of bacteria exist in the soil that are immune to attack by some other micro-organism.

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DEPARTMENT OF BOTANY

By WINIFRED E. BRENCHLEY

After the cessation of hostilities much of the war-time activity, especially that in association with the Chemical department, was brought to a close, and more time and apparatus was available for the normal work of the Botanical department. The minor element work was extended both in soil and water cultures, and investigations were initiated into certain field problems which had become of increasing importance during the war years.

A. MINOR ELEMENTS—MOLYBDENUM

The effect of molybdenum on plants continued to be approached from the two angles of toxicity and nutrition, the former in soil and the latter in nutrient solutions. The work in 1944–45 had strongly supported the hypothesis that the poisonous action of molybdenum is greatly influenced by the nature of the soil, and the factors causing this variation, as well as those bound up with the variability in the beneficial response to traces of the element, continued to be actively sought.

In *soil cultures* the general scheme of the experiments was the same as in 1944–45, though it was now possible to use larger pots for the strong growing tomatoes and Solanum, for which the small size of the pots previously available had introduced a serious limiting factor. Three of the same soils were again tested, Woburn soil and its compost, and the manganese deficient Isleham Fen soil. These were supplemented by two other fen soils, Littleport Fen, which was highly fertile, and Waterbeach Fen, which was definitely acid. In addition the allotment soil was replaced by a good loam, composted as before, and also the effect of manganese added to the Isleham Fen soil was tested in the case of flax.

Tomatoes again proved resistant to the harmful effects of molybdenum in several cases, and where response was obtained it tended to be irregular among the replicates. In Woburn soil the higher dose of molybdenum was fatal at an early date, and the lower dressing caused severe and irregular reduction of crop. The composting of this soil with peat enabled the tomatoes to withstand the harmful action of the lower dressing, and to produce a crop, again extremely variable in weight, with the heavier dose. In the manganese deficient Isleham Fen soil the crop was variable even in the controls, but on the average was quite as good as in some of the other soils. The addition of molybdate approximately halved the average crop for each progressive dose, but the poisonous effect was much less than in Woburn soil. No deleterious effect on the crop was found in any of the other soils tested.

The development of Solanum was adversely affected by both treatments of molybdenum in each of the five soils tested. The composting of both Woburn soil and top spit loam with peat reduced the poisonous action, expecially with the heavier dose, this being specially noticeable in the fruits and roots. In the Isleham Fen soil the controls were much reduced in size owing to the manganese deficiency, but the toxicity of molybdenum was even more marked here than with the other soils. Unfortunately it was

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not possible to test the effect of added manganese with this species.

With flax in most soils the toxicity of the lower dressing of molybdenum was hardly evident, but it was manifested by the higher dose. In the Isleham Fen soil the crop was much worse than in 1945, as the controls were only one third or one quarter the size, and no seed was produced in either untreated or treated plants. The addition of manganese improved growth all round, raising the dry weights, but leaving the toxic effect of the molybdenum well defined. Very little seed was formed in any of the treated plants, though the controls did better. It was an interesting confirmation that the two adverse factors, deficiency of manganese and excess of molybdenum, were able to function at the same time and that, despite the deficiency or the excess, the action of the other factor was clear and measurable.

In *nutrient solutions* striking beneficial effects had previously been obtained on a number of occasions with lettuce when small quantities of sodium molybdate (supplying 0·1 p.p.m. Mo) were added to the culture solution, and it seemed that this element was probably essential for normal growth for this crop. The results, however, were not always consistent and during the past year an attempt has been made to determine the cause for this lack of uniformity. Various crops, chiefly lettuce, red and wild white clover have been grown in different types of culture solution, and the effect of adding or withholding molybdenum noted in each case. Special attention has been paid to variations in the level of calcium supplied and the pH value of the different nutrient media selected. Lettuce is a quick growing plant and has already given some promising results, but as the varieties chosen were not suitable for summer conditions under glass confirmatory evidence cannot be obtained until next spring. Clovers, on the other hand, have a much longer growing period, and it will be necessary to carry them through the winter before all the available information from even one experiment will have been secured. Up to the present the two crops seem to be responding to the different treatments in a very similar fashion and symptoms of molybdenum deficiency have been well defined in both cases.

B. Vitality of buried weed seeds

Various aspects of the problem of weed seeds buried in the soil are still under consideration. In the experiments on Broadbalk wheat field periodic records of the weed seeds germinating from the soil samples taken in August, 1945, have been made and will be continued for the usual three year period. Until this is completed no comparison is available between the results of this sample and that of 1940, a comparison which will provide evidence as to the effect of the third 5-year fallowing cycle on three of the plots on the field.

Field observations and glasshouse experiments on dormancy and viability of wild oat seeds were continued. Germination of seeds of *A. fatua* vars. buried in soil to depths of 6 in. in pots continued even after the seeds have been at that depth for a year. Eventually it is hoped that information will be obtained about the viability of seeds kept in soil at greater depths, from which no seedlings have yet reached the surface. Preliminary investigations of dormancy in

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A. ludoviciana were made using glass germinators. Dr. Mann again sent samples and provided information about Wild Oats at Woburn.

An attempt was made to reduce the amount of viable seed produced by *A. ludoviciana* growing among wheat in the field by dusting the green ears with urethane (isopropylphenylcarbamate) mixed with kaolin, supplied by I.C.I. Although some sterility of Wild Oats was caused by the highest rate of application on the earliest date the method does not seem promising owing to the even greater sterility caused in wheat ears on which the powder fell.

Following an enquiry from the Isle of Man as to the best way of controlling annual nettle (*Urtica urens*), soil samples were sent from the infested area in order that an intensive study might be made regarding its habits of germination, with a view to being able to recommend suitable methods of control. Periodic records of the germination from both top and lower spit samples have been made and will be continued for several years. For comparison, similar records are being kept from soil samples obtained from a field known to be infested with the same species of Urtica at the Woburn Experimental Station. Both these soils are of a light sandy nature, and contain weed species, as well as *Urtica urens*, that do not occur in the heavy clay loam on Broadbalk, and these results will afford useful complementary information to that obtained at Rothamsted, quite apart from the Urtica question.

C.

In addition to the above main lines of enquiry work has been continued on the botanical composition of the herbage on Park Grass and High Field, and also other physiological work is in progress which has not yet reached the stage at which it can be reported.

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SECTION OF CROP PHYSIOLOGY

By D. J. Watson

As in previous years the Section was responsible for the general supervision of the field experiments from the laboratory side. An account of the programme of field experiments is given in a separate report.

The effect of yellows and mosaic virus diseases on the growth of sugar-beet

The Section has cooperated with the Plant Pathology department in designing field experiments, carried out over several years, to measure the loss of yield of sugar beet caused by infection with yellows virus. An account of the results has been published (43).

In 1945 an investigation of the changes in growth induced by infection with yellows virus was begun to determine the physiological causes of the large reduction in the yield of sugar. A field experiment was set up to test the effect of infection at the end of June or in early August of plants sown in mid-April or late in May. In 1946 a comparison was made in another field experiment between the effects of yellows and mosaic infection at two levels of nitrogen supply. On the plots to be infected with yellows infected aphides were placed on each plant, left for about 24 hours and then killed by nicotine fumigation. On the mosaic plots each plant was infected by rubbing one leaf with infected sap. In both years over 2,000 plants were infected in this way. A few plants on the healthy control plots became infected by spread from the infected plots or from outside sources, but the number of accidental infections was too small to affect the results seriously. A sample of about 30 plants was taken from each plot at intervals throughout the period of growth for the determination of fresh and dry weights of lamina, petiole (including the crown) and root, leaf area per plant, leaf number per plant, and the fraction of the total leaf area showing yellowing. The nitrogen content of the different parts of the plant, the sugar content of the root, and, in 1946, the carbohydrate content of the leaf lamina was determined.

In both years yellows infection at the end of June reduced the yield of sugar by nearly 50 per cent., as in the earlier experiments (43). Mosaic infection caused a smaller loss, about 14 per cent. of the yield of healthy plants. The later infection with yellows, in August, 1945, had very little effect. The loss of sugar yield caused by yellows resulted from three distinct effects on growth. The total leaf area of the plant and net assimilation rate were both reduced, and this decreased total dry matter production and hence the yield of roots. The percentage of sugar in the dry matter of the root was also depressed. Mosaic reduced leaf area and net assimilation rate, but did not change the sugar content of the root. Neither disease had any appreciable effect on leaf number; the effects on total leaf area per plant were attributable to a reduction in the size of individual leaves. With both yellows and mosaic the effects on total leaf area were relatively greater than those on net assimilation rate; loss of dry matter yield was mainly the result of the stunting of the leaves. Yellows caused a greater

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reduction in net assimilation rate in 1946 than in 1945; in 1945 the reduction was less, and in 1946 more, than could be accounted for on the assumption that the yellowed areas of the leaves were incapable of photosynthesis. The difference between the two years may be related to weather conditions; there was more rain and less sunshine in 1946 than in 1945.

The total carbohydrate content (sugars and starch) per cent. of dry matter of the leaf laminae infected with yellows was more than double that of healthy leaves, and the increase was mainly in reducing sugars. It was known previously that starch accumulates in leaves infected with yellows to a greater extent than in healthy leaves, and it was assumed that this was caused by restriction of the translocation of carbohydrate from the leaves. This was shown not to be true, for the loss of carbohydrate between sunset and sunrise was at least as great in infected as in healthy leaves. Infection with mosaic had no effect on the carbohydrate content of the leaf.

The two viruses also differed in their effects on nitrogen content; yellows reduced the nitrogen content of the leaf lamina, while mosaic increased it; yellows increased the nitrogen content of the petiole and root, but mosaic had no effect. Both viruses reduced the total nitrogen uptake.

Physiology of leaf growth

A. G. Morton was appointed in November, 1945, to continue the study of leaf growth, which was interrupted by the departure of R. S. de Ropp. Two papers (44, 45) were published on the results of de Ropp's work on the growth of leaves on excised stem-tips of rye in sterile culture.

Experiments were made to determine whether the effects of varying nutrient supply on leaf size are brought about by changes operating during the stage of cell-division, or later in the stage of cell-extension. A rapid method of estimating the total number of cells in a leaf by microscopic examination was worked out. Material was obtained from sugar beet, grown in pot-culture with varying supply of nitrogen, sodium chloride and water, and from field experiments on several crops, including the Classical experiments where the differences in leaf-size induced by varying nutrition are very large.

The examination of the results has not yet been completed. In the sugar-beet experiment it was found that cell number per leaf depended on nitrogen supply, but not on the supply of sodium chloride or water. All three factors affected cell-size. This result is in agreement with many other demonstrations of the importance of nitrogen supply in controlling meristematic activity.

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DEPARTMENT OF STATISTICS

By F. YATES

During the year 1946 we have suffered from our share of immediate post-war difficulties. In particular, shortage of statisticans trained and experienced in agricultural and biological work has made it very difficult to keep abreast of our commitments. Many more of our Universities are now recognising the need for providing training in research statistics for their students. In the long run this may be expected to bear fruit in an increased supply of able recruits, but for the moment the demands of the Universities for staff have accentuated the scarcity created by increased realization of the importance of statistics in many branches of research.

The position of the Department as a central Statistical Research Centre has been clarified, and work for other stations has continued to expand. Moreover, we have been able to give greater assistance this year than during the war years to the staff of other departments at Rothamsted, and members of the Department have made good progress in writing up completed work.

FIELD EXPERIMENTS AND EXPERIMENTAL DESIGN

In spite of difficulties the Department has begun to fulfil its new function as consultant in the problems of experimental design arising in other agricultural research stations in this country. During the course of the year the volume of these enquiries has been steadily growing. In addition, the volume of enquiries from our colonial dependencies, particularly in Africa, has been increasing concurrently with the revival of experimental work in these territories. The nature of these enquiries indicates that the Department has a useful function to perform in this respect.

The output of numerical analyses of the results of field experiments at Rothamsted has continued to be high, and we have also carried out a number of analyses for other stations.

Various members of the Department have given assistance to members of other departments at Rothamsted, particularly Entomology, Plant Pathology and Microbiology in the planning and analysis of their experiments.

Dr. Yates continued to serve on the Field Experiments Committee of the Agricultural Improvement Council and on the Supervisory Committee of the Grassland Improvement Station.

Four papers on experimental design have been published in the course of the year. Arising out of work at Rothamsted Mr. Finney completed his description of fractional replication (49). Mr. Kempthorne has given an account of the design and analysis of lattice squares with split plots, a type of design which has proved very useful in investigating the responses to the standard plant nutrients (N, P, K) in conjunction with different organic fertilisers (50). He also developed a simple method of generating complicated designs involving confounding and fractional replication (51). In the course of this work he carried out a further investigation on a point that has often troubled those concerned with modern experimental design, namely that if in a confounded

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experiment the responses to one of the factors varies from block to block (i.e. interacts with blocks), this will appear in the analysis as a spurious interaction between other factors. Using the results of the fertiliser trials on sugar beet conducted during the war years he confirmed the previous conclusion (based on much less extensive data) that there is no evidence that such interactions are of any importance in practice (52).

Animal experiments

In cooperation with the National Institute for Research in Dairying and the Rowett Research Institute a start has been made on the investigations of problems of design and analysis arising in experiments on animal nutrition and animal husbandry. The development of the technique of experiments on animals has lagged behind that on crops and it is hoped that during the next few years Rothamsted may be in a position actively to continue this work.

Sampling surveys and other sampling problems

Research on statistical problems arising in sampling surveys has been continued during the year. The review of recent developments in sampling and sampling surveys, read before the Royal Statistical Society in January, 1946 (as noted in the 1939–45 report), was well received and has provoked considerable discussion in the course of the year. Some research on systematic sampling has now almost been completed. Progress on the book on sampling surveys has unfortunately been held up by pressure of other work.

A short investigation by Mr. Anscombe and Mr. Quenouille was carried out on the problem of drawing balanced samples. Dr. Yates gave a course of lectures in the Michaelmas term, 1946, at the London School of Economics on "Survey Techniques and Problems". Investigations into the sampling errors of various types of sampling for botanical composition of herbage, etc., have been carried out by Dr. Boyd for Dr. William Davies of the Grassland Improvement Station and for Dr. Iorwerth Jones of the Welsh Plant Breeding Station.

Survey of fertiliser practice

During 1945–6 a survey of Fertiliser Practice was continued in the following provinces: Aberystwyth, Harper Adams, Midlands, Newcastle, Seale Hayne and Wye. Duplicated reports have been issued for the following counties: Cumberland, Gloucestershire, Huntingdonshire, Merioneth, Shropshire, Somerset.

The analysis of the surveys of the following counties was also completed: Durham, Holland division of Lincolnshire, Isle of Ely, Lindsey division of Lincolnshire, Northumberland, South Essex, Warwickshire, Westmorland, West Riding.

Publication of all the reports issued since the inception of the survey is under discussion.

Assessment of yields of grazed pastures by grass cutting techniques and other grassland problems

The work begun in 1945 on the evaluation of the yield of pasture by grazing and by grass-cutting in conjunction with the

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Chemistry Department and with the Grassland Improvement Station was continued at Rothamsted in 1946; grass-cutting was also undertaken at one of the R.A.S.E.'s grazing trials at Old Warden, Bedfordshire. The statistical analysis of these experiments and of three others carried out in the Northern, East Midland and Welsh Provinces has been carried out by Dr. Boyd and a duplicated report has been issued.

Mr. A. E. Jones carried out an investigation into the difficulties involved in estimating errors from the live-weight increase of grazing animals. This, however, has still to be reported.

National farm survey

Mr. Kempthorne and Dr. Boyd used the data obtained during the survey to investigate the relationship between the rental value and stock-carrying capacity of land (59). A similar investigation on the labour requirements of farms is in preparation. Maps showing the average rent per acre for every parish in England and Wales have been prepared and form a valuable field for further research. They are of particular interest to the Soil Survey Department.

Mr. Kempthorne has published an account of the methods of analysis by the use of punch-cards which was developed in connection with the analysis of the National Farm Survey (54).

Resazurin research scheme

This work has made excellent progress during 1946 under the supervision of Mr. Kempthorne, assisted by Mr. Quenouille. The original enquiries have been extended to cover investigations on the alcohol precipitation and clot-on-boiling tests which appear for a number of purposes to be better than the Resazurin test; and on the temperature compensation of keeping quality tests in general. Two papers were prepared by Mr. Kempthorne before he left, which it is intended to publish shortly. A further general report on the progress of the scheme has been prepared. It is hoped that a comprehensive report on the whole of the conclusions will be published in the fairly near future when certain further investigations have been completed. The Department will continue to co-operate with the National Agricultural Advisory Service and with the National Institute for Research in Dairying in the supervision of the statistical aspects of the scheme.

Advisory entomologists conference

Mr. Anscombe has acted as statistical advisor to the Advisory Entomologists, and in particular has been concerned with two matters:—

(1) A uniform procedure for estimating potato eelworm cyst populations has been evolved, so that results of sampling carried out in different parts of the country will be comparable and the stage is set for a national survey if that should be required at any time.

(2) A scheme of observation of certain pest insects at stated times of year (the "calendar insects") has been launched, with the object of recording the fluctuation from year to

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year in insect population and in damage done to susceptible crops, and seeing what correlation exists between them. The first year's observations (1946) have provided not only interesting information about the distribution and intensity of infestations but also useful experience of possible methods of sampling. A revised programme of observations for 1947 has been prepared.

Arising from meetings with the Advisory Entomologists there has been some direct advisory work with individuals, in particular regarding the sampling of swede seed crops for insect damage (Wye Agricultural College).

An investigation into methods of fitting negative binomial distributions to insect counts is in progress.

Institute of Agricultural Parasitology

Extensive trials are to be made of the new insecticide DD against potato eelworm and the Institute of Agricultural Parasitology has been in touch with Mr. Quenouille and Mr. Anscombe on the design and analysis of these trials. A preliminary experiment was conducted at Gamlingay in 1946, in order to gain experience of field and laboratory techniques, in particular of eelworm sampling techniques. The results are being analysed.

Other work

Dr. Yates has continued to serve on the Scientific Advisory Committee of the Ministry of Works. He gave a paper to the Agricultural Educational Association on the place of statistics in agricultural research (61), and prepared a short paper for "Contact" (62).

Mr. Finney published a paper based on work at Rothamsted on the analysis of factorial series of insecticide tests (53).

Mr. Kempthorne spent two months in Greece as part of an international team of observers on the conduct of the elections. A general report on the statistical aspects of this work has subsequently been prepared (60).

Dr. Boyd completed an investigation on the results of experiments on the manuring of beans and peas. The results of all available fertiliser experiments on these crops were summarised and reported (57). The paper also includes an account of the current manurial practice for these crops as shown by the survey of fertiliser practice. A more general duplicated report was prepared by Dr. Boyd and others for the Agricultural Improvement Council.

Mr. Anscombe published two papers concerned with sampling inspection (55, 56). He also delivered a lecture to the Science Masters Association entitled "Statistics in the School Science Course".

Mr. Quenouille assisted members of the physics department in the mathematical theory required for some of their experiments. He has also published a paper on the problem of random flights (48).

Mr. A. E. Jones completed his thesis on random sequences for Ph.D. at London University (47) and was subsequently awarded his degree. He also published a paper on the routine estimation of dispersion from large samples (46).

Dr. Cashen revised her report on the influence of rainfall on the

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yield and composition of permanent grass at Rothamsted in a form suitable for publication (58).

In addition to supervising numerical analyses of the field experiments Mr. Weil carried out field work in connection with the factory sugar beet and other outside centre experiments.

STAFF

Mr. A. E. Jones left in October, 1946, to take up a lectureship at Imperial College. Mr. E. G. Davy joined the staff in April, 1946, from the Royal Air Force, and left in November, 1946, to take up an appointment as Assistant Director at the Observatory, Mauritius. Mr. O. Kempthorne left in December, 1946, to take up an appointment as Research Associate Professor at the Statistical Laboratory, Iowa State College, Ames, Iowa. Mr. M. H. Quenouille was granted leave of absence for a year's research at Cambridge in the academic year 1946–7 and has recently been appointed Lecturer in Statistics at Aberdeen University. Mr. R. T. Eddison, Mr. B. M. Church, Miss Pamela Clarke and Mr. P. Robinson were appointed to the staff at the end of 1946 but did not take up their appointments until 1947. Mr. Robinson is holding a temporary appointment and is returning to Cambridge to read for the Diploma in Mathematical Statistics.

Mr. D. R. Read spent three months from May to August, 1946, in the Department. He was then seconded as Assistant Statistician to the National Institute of Poultry Husbandry, Harper Adams Agricultural College.

Mr. J. Weil has been transferred to the Field Experiments Section where he is primarily concerned with the supervision of field trials.

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DEPARTMENT OF PLANT PATHOLOGY

By F. C. Bawden

Mr. L. Broadbent was given a grant by the A.R.C. for work on potato aphides and replaced Mr. J. P. Doncaster, who returned to the British Museum in January, 1946. Mrs. J. Bradley resigned her post as assistant to Mrs. Watson and was replaced by Miss B. M. Hamlyn in November, 1945. Dr. A. Kleczkowski, who has worked in the Department with a Beit Memorial Fellowship and other awards since 1940, was appointed to the staff in January, 1946. In June, 1946, Mr. J. Blencowe was awarded a research grant by the Sugar Beet Research and Education Committee to work with Mrs. Watson on sugar beet yellows. Mr. I. Macfarlane, Mr. R. P. Chaudhuri and Dr. K. S. Bhargava joined the Department as voluntary workers. During the course of the year the Department has had many visitors, from all parts of the world, who have stayed for periods ranging from one day to six weeks.

In November, 1945, Mr. Bawden visited Spain at the invitation of the Higher Council for Scientific Investigations and gave a course of lectures on virus diseases in Madrid. Mr. Bawden also gave the Cantor Lectures of the Royal Society of Arts. At the invitation of the Directie van de Zuiderzee Polders, Mr. Garrett visited Holland in July, 1946. Miss Glynne also visited Holland in connection with her work on eyespot of wheat and Mrs. Watson visited Holland and Belgium on behalf of the Sugar Beet Research and Education Committee. At the request of the Irish Sugar Corporation Mrs. Watson also visited Eire.

Virus diseases

1. *Laboratory work*

Considerable attention was again given to the various treatments that liberate viruses from infected leaves, and it was found that tobacco plants suffering from mosaic contain much more virus than was previously suspected. This virus sometimes amounts to one-third of the total insoluble nitrogen of the leaf, and accounts for as much as 10 per cent. of the dry matter. Less than a third of the total virus is obtained in the sap (68).

Electron micrographs of preparations of tobacco mosaic virus fractionated by differential ultra-centrifugation revealed particles of different sizes and lengths. The most slowly sedimenting fractions were mainly composed of small, almost spherical particles, but these particles readily aggregated to produce rods of various lengths (74).

The joint work with Mr. L. V. Chilton of Messrs. Ilford, directed to producing more suitable emulsions for the electron microscope, has continued. Attention has this year been directed chiefly towards emulsions desensitized to light, more concentrated and more highly conducting emulsions.

Potato virus X was also obtained from leaf residues by fine grinding and incubation with snail enzymes, but not by trypsin which destroyed the virus in the residues. As with tobacco mosaic

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virus, potato virus X preparations obtained by grinding leaf residues have different properties from those of preparations made in other ways, probably because they contain a greater proportion of small particles. These particles can be aggregated into long rods by suitable treatments. New strains of virus X have been found which reach higher concentrations in infected sap than those previously used. Yields of 2 g. per litre of sap have been obtained with some of these. The manner in which this virus inactivates and breaks down with various treatments has been studied.

A study was made of substances that reversibly inhibit the infectivity of tobacco mosaic virus. Most of these are substances charged oppositely from the virus and combine with it, often to produce a visible precipitate. The enzyme ribonuclease inhibited infectivity of the virus much more strongly than did other tested proteins which combined with it (78).

2. *Glasshouse work*

Considerable attention has been given to the conditions that affect the susceptibility of plants to infection with viruses. Light intensity was the most important of the variables tested. Reducing illumination in summer to one-third increased susceptibility to tobacco necrosis, tomato bushy stunt, tobacco mosaic and tomato aucuba mosaic viruses by more than five times. Reducing the light intensity also increased the virus content of sap from infected leaves (69).

Fertilisers also influenced susceptibility of plants to infection and the concentration of virus attained in infected plants. Increases of both nitrogen and phosphate reduced the number of local lesions produced by tobacco mosaic virus on *Nicotiana glutinosa* and by aucuba mosaic virus on tobacco. Potash had no significant effect. Phosphate significantly increased the virus content of infected plants, whereas nitrogen gave only a slight increase, and that only in the presence of sufficient phosphate. Virus preparations made from plants given widely different fertilisers did not differ from one another in their infectivities.

Several strains of potato virus Y have been differentiated by their reactions on a range of commercial potato varieties. These vary in the symptoms caused on Majestic from a severe leaf drop streak to a faint mottle. All these forms were transmitted by a number of different aphides, but no vector has been found for the aberrant strain, potato virus C, which causes top-necrosis in Majestic.

Different strains of potato virus X spread at different rates in the field, but even the most rapidly spreading strains infected only 10 per cent. of the healthy potato plants in contact with infected ones. Spread occurs much more rapidly between infected and healthy tomatoes, and in this plant root contact is as effective as foliage contact in spreading virus X (79).

A tobacco necrosis virus was isolated from the leaves and flowers of a naturally-infected *Primula obconica*, which showed no symptoms and in which the virus seemed to occur only in isolated areas. Tobacco necrosis viruses enter and multiply locally in primulas without producing symptoms; movement from the

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inoculated regions occurs only rarely and fails to give a full systemic infection (67).

The properties of dandelion yellow mosaic virus which causes a severe necrotic disease of lettuce were studied. It is transmitted by the aphides *Myzus ornatus*, *M. ascalonicus* and *Aulacorthum solani*, whereas lettuce mosaic virus is not transmitted by any of these vectors, but by *Myzus persicae* (77).

A yellowing disease has been found associated with a new variety of sugar beet in Ireland. All stocks of the variety were affected, and as the condition appears to be spreading to other varieties it may be a virus disease, possibly related to virus yellows, but this awaits confirmation.

Most of the diseased turnips and swedes examined during the year proved to be infected with cauliflower mosaic virus; the symptoms caused by this vary greatly with fertiliser treatment, and can be completely inhibited by potash deficiency. Both cauliflower mosaic and cabbage black ring-spot viruses (Turnip Virus 1) were shown to be non-persistent viruses.

Common pea mosaic virus was also shown to be a non-persistent virus. Of the three aphides, *Myzus persicae*, *Macrosiphum pisi* and *Aphis fabae*, *M. persicae* proved to be the most effective and *M. pisi* the least effective vector. For enation pea mosaic virus, on the other hand, *M. pisi* proved the best vector.

3. *Field work*

In cooperation with the Crop Physiology Section an experiment was made to determine the effect of infection with sugar beet yellows and mosaic viruses on growth and yield of beet. With the Insecticides Department experiments were made to test the effect of various insecticides, including D.D.T. and Gammexane, on spread of beet yellows virus from infected seed plants. An experiment was also arranged for the British Sugar Corporation to provide material for testing the effect of yellows on sugar content and "Noxious Nitrogen" of the beet.

In cooperation with Advisory Mycologists and others experiments with potato crops on the effect of date of planting and date of lifting, and on the effect of roguing on the spread of rugose mosaic (potato virus Y) and leaf roll, have been continued in Herts., Lincs., and Derby. Results of these experiments will be available in 1947. In 1945 the spread of rugose mosaic was smaller than usual. Leaf roll also increased less than usual in the Southern counties, but more than usual in Northern counties. Most of the transmission of rugose mosaic, and approximately half that of leaf roll, had occurred by the beginning of August. At Rothamsted roguing secondarily diseased plants in mid-July did not substantially reduce the spread of either rugose mosaic or leaf roll. In 1946 the survival of volunteer potatoes from the previous year's crop was of the usual order of from one thousand to four thousand per acre, but only few volunteers survived on the Rothamsted and Woburn Experimental Farms.

A survey of aphides overwintering on field and garden Brassicae, in glass and chitting houses, and on *Prunus* spp. was made during the early months of the year in Beds., Derby., Herts. and Lincs. The relatively mild winter and warm spring enabled the aphides

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to overwinter and achieve large populations on their winter hosts in many districts. A new site for the overwintering of aphides in this country was discovered, large numbers of the insects being found in mangold and swede clamps. During the autumn counts of aphides were made on mangold and swede crops in Derbys., Herts. and Lincs. Aphis counts were made on potatoes at Rothamsted, in Notts., Lincs., and Derby. Counts were also made by advisory entomologists and other cooperators at nine additional centres. Eighteen adhesive aphis traps were operated in connection with these experiments. Aphis populations of potatoes in the south of England were very small throughout the season; in Derby. and Lincs. they were below those of the previous year, but were still considerably higher than in the south. Trap catches were very small compared with past years.

Mycology

Violet root rot (*Helicobasidium purpureum*)

A laboratory study of factors affecting the production and growth of the mycelial strands of *H. purpureum* was completed during the year. Progressive infection and rotting of the potato tubers used in this study was obtained only when the tubers were attached to the parent plant and still growing; harvested tubers buried in glass jars of soil could be used, however, for measuring the production and epiphytic growth of mycelial strands in the laboratory. Production and growth of strands increased with concentration of nutrients in meat-malt agar, and especially with that of the malt constituent. Soil acidity depressed strand growth at medium and low but not at high soil moisture content, and not in the soil sand mixture (85).

A technique has been devised for investigating the survival in soil of the sclerotia of *H. purpureum*. Sclerotia are produced on agar plates and buried in glass jars of soil kept in the laboratory, and samples are tested at intervals for viability on carrot seedlings raised in the glasshouse. A new mycological tool, the multiple-point inoculating needle, was devised for this work (86). Preliminary results have indicated that longevity of sclerotia decreased with increase in nutrient concentration of the substrate on which they were formed, and especially with increase of nitrogen.

Clubroot (*Plasmodiophora brassicae*) *of crucifers*

A study of resting spore survival in *P. brassicae* by means of the infected root hair count method has indicated that, under suitable soil conditions of light texture, moderate acidity (pH 6·0) and high moisture content (80 per cent. of saturation), some 90 per cent. of the resting spores may germinate spontaneously in the first few weeks, or even days, after their incorporation with fallow soil, in spite of the absence of host plant roots. A proportion of the spores, however, do not germinate spontaneously in fallow soil, and so serve to perpetuate the organism. Experiments with dormancy-breaking stimulants are in progress.

Eyespot (*Cercosporella herpotrichoides*) *of cereals*

Regional surveys in E. Anglia and Northants showed increasing trouble from eyespot resulting from intensive cereal cultivation.

The yield of wheat grown in pots and infected by *Cercosporella*

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herpotrichoides was depressed while that in healthy control plants was little affected by too high a seed rate. Spraying with sulphuric acid in March increased the yield of infected plants, but not of healthy control plants. Spraying too late, i.e. mid-April, had little effect on yield of infected but reduced that of control plants. In a factorial field experiment on infected wheat, spraying with sulphuric acid in March reduced the area lodged from 90 to 30 per cent. Increase in seed rate and increase in top dressing with ammonium sulphate increased the area of crop lodged. Late-sown crops generally yielded less than early sown except with long strawed varieties which were badly lodged through disease in the earlier sowings.

The susceptibility to *C. herpotrichoides* of different hosts decreased in the following order: wheat, barley, oats, wild oats, rye.

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Take-all of Wheat and Barley

The take-all disease of wheat and barley, caused by *Ophiobolus graminis* Sacc., has been one of the main problems studied in the Department for the past 10 years. Mr. S. D. Garrett started his investigations of soil conditions that influence the occurrence of take-all at the Waite Agricultural Research Institute of Adelaide, South Australia, in 1932, and continued them when he came to Rothamsted in 1936. With the successful completion of a field experiment on the control of take-all, this comprehensive investigation has now been concluded. In the succeeding pages Mr. Garrett summarizes the results and conclusions to be drawn from his work.

Preliminary investigations in the glasshouse using earthenware pots containing 4 kg. of soil gave disappointing results, so a more precise method was sought. This was achieved by working in the laboratory and using glass tumblers holding 2–300 gm. soil as containers. The glass-tumbler method was first used to study the effect of soil conditions upon the rate of growth of the runner hyphae of *O. graminis* along the roots of wheat seedlings; growth was more rapid in light-textured than in heavy-textured soils, which agreed with the greater prevalence of take-all on light-textured soils in South Australia. Growth of the runner hyphae was found to be most rapid around 24° C., and wheat seedlings were most severely affected by the disease at this temperature (1).

Growth of the hyphae of *O. graminis* along wheat seedling roots was found to increase both with improvement in soil aeration and with rise in pH value of the soil, being most rapid in light-textured alkaline soils. Evidence was put forward for the hypothesis that the factor limiting rate of growth of the runner hyphae in heavy-textured and in acid soils was the accumulation of respiratory carbon dioxide in the micro-climate of the root surface zone. Good correlation was obtained between soil conditions optimum for growth of runner hyphae along the roots in these laboratory experiments, and those known to favour the field incidence of take-all in South Australia and elsewhere. This coincidence was epitomised as follows: "Rate of growth of the fungus along the root system must be one of the chief factors determining whether

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the attack be fatal to the plant or not. The speed with which the fungus reaches the crown region from one or more foci of infection on outlying parts of the root system may be the decisive factor in the recovery or otherwise of the plant. Once the fungus has established itself around the crown, new secondary roots may be destroyed almost at their inception" (2, 3).

Attention was next concentrated on the effect of soil conditions upon the survival of *O. graminis* in infected crop residues. It was thought that soil conditions unfavourable for vegetative activity, but not for dormancy of the fungus, would tend to promote longevity, and this was found to be so. The fungus survived for longer in air-dry soil, in moist soil at 2°–3° C., or in water-logged soil, than in soil at medium moisture content (50 per cent. saturation) and a temperature of 17°–20° C. But under soil conditions favourable for general microbiological activity, the factor limiting survival of *O. graminis* was found to be the supply of nitrogen, whether contained in the original infected plant material or supplied during its decomposition by the surrounding soil. All forms of nitrogen added to the soil, whether organic, ammonium, or nitrate nitrogen, increased the survival of *O. graminis*. Conversely, nitrogen-poor organic materials, which undergo rapid decomposition in the soil, such as glucose, starch and grass-meal, shortened the life of *O. graminis* by taking up available nitrogen from the soil. It was also shown that the life of the fungus could be greatly shortened simply by crowding the infected straws closely together with the minimum of surrounding interstitial soil. Finally, *O. graminis* was found to survive for longer in fallow than in soil under growing plants of trefoil, oats or mustard, an effect which was attributed to absorption of available soil nitrogen by the green plants.

In soils well supplied with nitrogen, and therefore favourable to longevity of *O. graminis*, the fungus was found to continue a slow mycelial development within the cells of the infected host tissues. In tissues deprived of nitrogen, however, the fungus did not continue to develop, presumably because of lack of the nitrogen required to form new hyphal branches. It appears likely that the old hyphae eventually die of carbohydrate starvation, because the surrounding substrate is exhausted; survival of the fungus is somewhat prolonged by a twice-weekly shaking of infected straws in 3 per cent. dextrose solution (4, 5, 6).

In the field *O. graminis* persists in the soil not only in infected residues of wheat and barley crops, but also in the living and dead infected roots and haulms of susceptible grass species. The relative importance of different species of grasses in the propagation of *O. graminis* was investigated as directly as possible, by infecting grasses with a minimal dose of non-persistent inoculum. The grasses were then grown in boxes for 2 months in the glasshouse, after which time the turves were inverted in the boxes, and the survival of *O. graminis* was assessed by planting test wheat seedlings at approximately monthly intervals up to 5 months. Of 16 grass species tested, *Agrostis* spp. were the most effective as propagators of *O. graminis* and *Phleum pratense* the least; *P. pratense* was virtually a non-propagator. The two rye-grasses, *Lolium italicum* and *L. perenne*, were 7th and 8th on the list of effectiveness

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as propagators, but it must be emphasised that the grasses were only grown for 2 months before the sods were inverted. Subsequent field surveys have shown that temporary leys containing rye-grasses do not usually lead to outbreaks of take-all in the first wheat crop immediately following them; it therefore seems possible that susceptibility of the rye-grasses to infection by *O. graminis* decreases with age (7).

Oats has been reported from most countries as highly resistant or immune to take-all. In view of persistent reports of oats affected by take-all in Wales, infected material was secured from there, and the pathogen isolated. This proved to be a biologically distinct strain of *Ophiobolus graminis*, which was a vigorous parasite of oats as well as of wheat and barley, whereas the high resistance of oats to infection by *Ophiobolus graminis sensu stricto* was confirmed in these experiments. The biological strain from Wales was also found to differ morphologically from *O. graminis* proper, inasmuch as the ascospores were significantly longer, a difference which has since afforded a reliable method for identifying the oat-attacking strain. This biological strain has been elevated to varietal rank, under the name of *Ophiobolus graminis* var. *Avenae* E. M. Turner (8). *O. graminis* var. *Avenae* has since been identified on oat crops grown in the West and North of England, and in Scotland (9), but it has not so far been found in the South or East of England.

The investigations so far described have been concerned with *O. graminis* as a soil-borne fungus, and it is therefore necessary to point out that the fungus can be air-borne, by means of its ascospores, which are forcibly ejected from the perithecia formed on infected stems of cereals and grasses (10). All early attempts to obtain infection of the roots of wheat seedlings with ascospores failed. Success was later obtained, however, when seedlings raised in sterile soil were inoculated. Infection was also obtained in sterile sand, though not in non-sterile sand. It seems that, in the absence of accessory nutrients, the food reserves of the ascospores are insufficient for the initiation of root infection. In sterile sand, accessory nutrients adequate for establishment of infection are thought to be provided by root excretions, which must remain wholly available to the germinating ascospores, but in unsterile sand the root excretions are possibly assimilated by the micro-organisms of the rhizosphere before the germinating ascospores can benefit therefrom (11).

The account of the epidemiology of take-all thus far presented is incomplete inasmuch as nothing has been said of the reaction of the host plant to infection. The most important factors affecting host resistance seem to be (1) supply of plant nutrients (2) temperature. It seems probable that the resistance of the wheat plant to infection decreases with rise in temperature, and that this, as well as increased activity of *Ophiobolus*, contributes to make 24° C. the optimum temperature for development of take-all. The effect of plant nutrients upon the development of the disease was studied in sand culture, under full rates and one-third rates of nitrogen, phosphate and potash manuring. In plants grown under two-thirds deficiencies of N, P and K, infection reduced yield by 24, 49 and 21 per cent. respectively, of that of the non-inoculated control

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plants. But in plants grown with full nutrients, infection failed significantly to reduce yield. This effect of liberal manuring with NPK in reducing loss of yield caused by infection can be explained by the increased production of new crown roots by the host plant. Many of the extra new crown roots produced as a result of manuring may remain free from infection for a considerable period; the chances of disease escape increase with the distance of *O. graminis* from the site of root initiation, the crown. The apparent tolerance to infection of the fully manured plants is not brought about by any increase in resistance of roots to infection, but by this disease escape mechanism; indeed, in this experiment, the roots of plants grown in full nutrient solution were actually more severely infected than were those of plants grown in the nitrogen-deficient solution. Abundance of nitrogen therefore seems to decrease the resistance of individual roots to infection, but, by increasing the total number of new roots produced, to increase the chances of disease escape for the plant as a whole (12).

Concurrently with these investigations in the laboratory and glasshouse the behaviour of the take-all disease was observed in the field by means of crop surveys, which were made chiefly in the Southern Advisory Province, in collaboration with Mr. W. Buddin. In the long perspective of traditional English agriculture, take-all has not been a disease of much importance, as it has been kept within bounds by the practice of crop rotation. Two exceptional circumstances, however, have favoured the disease and made possible these field investigations: firstly, the temporary popularity of intensive "mechanised" cereal growing under the economic difficulties of the early nineteen-thirties, and, secondly, the intensive cereal growing rendered necessary by the 1939–45 War. In particular, the growing of several consecutive crops of wheat upon the site of ploughed-up grassland favoured the development of take-all. The surveys also showed the importance of certain perennial rhizomatous grass weeds, notably species of *Agrostis* and *Holcus*, and *Agropyron repens*, as propagators of *O. graminis*; the prevalence of such weeds often completely nullifies the value of a rotation otherwise adequate for the control of take-all (13).

From the experience gained in the laboratory and glasshouse investigations and the field surveys described above a field experiment on control of take-all was designed and carried out at the Woburn Experimental Station, from 1943 to 1946, in collaboration with Drs. D. J. Watson and H. H. Mann. In view of the fact that take-all can be controlled by a 3 or 4-course rotation, or often indeed by a 2-course rotation, such as that of sugar beet and barley, the only practical problem to be solved was that of controlling the disease under continuous cultivation of a susceptible cereal crop. Field experience has repeatedly shown that it is difficult to control take-all in consecutive crops of autumn-sown wheat, as the interval between harvest and drilling of the next crop is too short for hyphae of *O. graminis* in the infected crop residues to die. More latitude is allowed by a succession of spring-sown wheat or barley crops; in particular, the system practised by Mr. F. P. Chamberlain, of Benson, Oxfordshire, for the last 15 years, seemed worthy of trial. The Chamberlain system consists essentially of the sowing of trefoil (*Medicago Lupulina*) along with the barley in spring; the trefoil

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makes a good growth in autumn after barley harvest, and is ploughed-under in late winter or early spring as preparation for the next barley crop. In theory, this system appears ideal for the control of take-all; the active growth of the trefoil in autumn should deprive *O. graminis* in the infected barley residues of the nitrogen essential for its prolonged survival, whereas liberation of nitrogen from the ploughed-under trefoil in late spring should help the following barley crop to tolerate infection from the over-wintering inoculum.

In this field experiment at Woburn, 6 autumn treatments were compared, *viz.* growth of trefoil with and without sulphate of ammonia, ploughing-in of additional straw with and without sulphate of ammonia, early ploughing without other treatment, and late ploughing with stubble cleaning but no other treatment. Half the barley plots received sulphate of ammonia in spring, and half received a combined spring dressing of phosphate and potash; the number of treatments in the factorial design was 24 ($6\times2\times2$). Wheat was drilled in autumn, 1943, and was followed by spring-sown barley in 1945 and again in 1946, so that in 1946 the cumulative effect of 2 years' treatments was obtained. Both in 1945 and in 1946 sulphate of ammonia in spring substantially reduced disease rating and increased yield; combined phosphate and potash produced a similar effect, which was greater in the second year. For that half of the experiment receiving sulphate of ammonia in spring, the best autumn treatments both for disease control and for grain yield were those in which trefoil was grown. Application of sulphate of ammonia to the trefoil in autumn increased grain yield but also slightly increased the incidence of take-all; the effect of autumn nitrogen in assisting overwintering survival of *O. graminis* evidently counterbalanced its effect in promoting disease escape of the growing barley crop in the following spring. It seems likely, therefore, that if the sulphate of ammonia had been applied not to the trefoil in autumn but to the barley in spring, so as to have doubled the spring dressing, it would have reduced incidence of take-all and given a greater increase in grain yield.

In the foregoing account of investigations at Rothamsted no mention has been made of previous or contemporaneous work by other investigators; references to this work can be found in the original papers cited here, and also in a review published in 1942 (14).

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DEPARTMENT OF BIOCHEMISTRY

By N. W. PIRIE

At the invitation of the Worcester Foundation for Experimental Biology Mr. N. W. Pirie went, in February, 1946, to spend a year there as Associate Professor. Dr. J. Gregoire, who had been working in the Department, returned to France in January. Some of the work done has been carried out in collaboration with the Departments of Plant Pathology, Crop Physiology and Chemistry.

The main line of work has been to find the effect of mineral fertilisers on virus infected and healthy plants. Glasshouse-grown tobacco plants infected with tobacco mosaic virus and potato infected with potato virus ffi were examined. Sugar beet from a field experiment with healthy, mosaic-infected and yellows-infected plants was analysed at six different stages of growth. Broadbalk wheat plots were sampled on two occasions.

With local multiplication of tobacco mosaic in tobacco there was no consistent difference between infected and healthy plants, whereas with systemic infection significant differences were found. These included an increase in the nitrogen, phosphorus and potassium content as a percentage of the dry matter in infected plants, however as the weight of plants in infected groups was less than those of healthy the total amount of these elements taken up was smaller.

Mosaic infection in sugar beet led to an increase in the nitrogen and phosphorus content as percentage dry matter while yellows infection caused a decrease.

There were large differences in the pectase content of tobacco plants with different fertiliser treatments, the amount varying with the nitrogen content of the plants.

A sensitive method for the estimation of protease which allows its determination in small quantities of saps (of the order of 1 ml.) in spite of its usual very low level has been developed.

The protease content of all the plants with different fertiliser treatments and virus infection was determined. It was found that the use of potassium as a fertiliser had little effect on the protease content per gram dry matter in tobacco plants but that phosphorus led to an increase in protease per gram dry matter and nitrogen to a decrease. Systemic infection increased protease per gram of dry matter. The protease of the green leaves of a number of plants has been examined and some progress in its purification and the elucidation of its properties has been achieved.

Work has been continued on an alkali producing mechanism that occurs in the minced leaves of certain plants that have a high calcium content. It was found that these plants have an exceptionally high insoluble inorganic phosphorus content. The pH rise can be produced with the fibre of leaves that do not normally show it by soaking in neutral phosphate solution and milling with calcium carbonate.

It has been shown that pyrophosphate is as effective an extractant (at least on organic soils) as the almost universally used NaOH and has the advantage that it does not degrade what it extracts. Degradation of the organic matter in NaOH extracts is

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indicated by production of free ammonia, the formation of an easily dialysable fraction and an uptake of oxygen. Activated charcoal has been found to adsorb nearly all the nitrogen remaining in solution after acidification of the organic-matter extracts. Preliminary tests have indicated that about 2 per cent. of the nitrogen of soils is amino-sugar nitrogen.

A close correlation has been shown between the ability of certain compounds to extract metals from soils and their ability to extract the organic-matter of soils. The metals estimated in the extracts were copper, manganese and iron and the nitrogen content of the extracts was used as an index of their organic-matter content. Pyrophosphate and various hydroxycarboxylic acid salt solutions proved to be good extractants both of metals and of organic-matter, whereas orthophosphate and the corresponding unsubstituted carboxylic acids which do not form soluble complexes with the metals also proved comparatively ineffective as extractants of organic-matter. This suggests that some of the polyvalent metal of soil exists as insoluble metallo-organic complexes with some of the organic-matter. The hypothesis is strengthened by finding that the precipitates obtained by the addition of manganese, copper or iron salts to preparations of soil organic-matter show just the same type of solubility as is shown by the organic-matter in the soil.

It has previously been shown that neutral solutions of sodium pyrophosphate extract considerable amounts of manganic manganese from soil in the form of a pyrophosphate manganiate complex. Further work has shown that neutral solutions of the sodium salts of various hydroxy carboxylic acids also form soluble complexes with the manganic manganese of soils. It is suggested that such acids may be of importance in maintaining manganese in an available form in soils.

Results from differential poisoning techniques carried out in the new perfusion apparatus have indicated that copper plays some essential part in nitrification in soil. Zinc is a powerful inhibitor.

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DEPARTMENT OF ENTOMOLOGY

By C. B. WILLIAMS

During the year the permanent scientific staff has consisted of C. B. Williams, H. F. Barnes and A. C. Evans. An Indian post-graduate student S. N. Banerjee has worked in the Department since March, 1946; and in April C. G. Johnson was appointed to an A. R. C. grant to investigate the long distance movements of insects, and particularly *Aphis fabae*. W. S. Guild has held a grant from the Agricultural Research Council for the study of earthworms. W. S. Richards has also worked during the year on the ecology of British Harvest Mites (*Trombicula*) with a grant from the Medical Research Council.

A.—Field work on the relation of activity and abundance of insects to weather conditions was resumed at the end of April, 1946, as the use of light traps was again possible after the war. Three traps were in use during the year, instead of one in the pre-war years, as it is proposed in the future to pay less attention to the total number of insects and more to single species. Greater total numbers must be captured to get sufficiently high numbers of one species for statistical analysis.

All calculations so far completed support the results obtained in the earlier years.

Work on the analyses of mixed insect populations—arising originally out of the light trap samples—has also continued and developed, and once more the new year's samples obtained from the trap have been found to support the previous results. The "Index of Diversity" as a measure of "richness" of a population has been found to be a valuable conception in understanding the relative numbers, and changes in numbers, of species under natural conditions when in contact with many other species. Botanical applications of the same technique have also been found. This work is developing into an important branch of "Synthetic" field ecology as opposed to analytical laboratory studies, and may prove to be fundamental in understanding insect outbreaks under the complicated conditions of field agriculture.

Work on insect migration has continued to occupy a small amount of time, and this has chiefly been used in filing records received from observers in this country and abroad. Several papers have appeared during the year which were written in previous years.

B.—The twentieth successive year of Dr. Barnes' long-term study of the incidence of the wheat blossom midges on Broadbalk was successfully completed. There was a still further increase in the numbers present and the following table shows a comparison of the last three years. It is quite obvious that these midges

	Numbers of larvae in 500 ears of wheat			*Per cent. grain infestation*		
	1944	1945	1946	1944	1945	1946
C. tritici	1,030	24,643	29,638	1	6·8	13·3
S. mosellana ...	133	3,557	3,853	½	11·0	13·3

caused damage to wheat both in 1945 and in 1946. There have now been four peaks of high infestation during the last twenty

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years. It can be expected that the peak of the present outbreak has been reached and that during the next two or three years the numbers of midges will drop, while the numbers of their natural enemies are increasing. The presampling necessary to establish the correct sampling date was done during 1946 on Plot 14 owing to the prevalence of wild oats on Plot 2. The study of the longevity of the larvae of these midges in the soil was continued. *S. mosellana* collected in July, 1939, still continued emerging in 1946, and about 60 per cent. of the 1940 and 1941 larvae have now emerged.

It is obvious that this long-term study is still yielding unique results and should be continued as long as possible.

A joint study by Dr. Barnes and Mr. J. W. Weil of slugs in Harpenden gardens was brought to a temporary close in December, 1945. It was restarted in September, 1946, in both Bedford and Harpenden with a view to finding out if the results obtained in Harpenden are equally applicable in other places. The second part of the results of the first two years' work was published in the November, 1945. This contained three coloured plates. These consisted of paintings generously provided free by Miss Evelyn M. Tuke, and the publication costs were defrayed entirely by Messrs. H. R. Napp, Ltd., the manufacturers of metaldehyde used in baiting slugs.

A paper embodying the results of the third and fourth years' work has now been completed and the results of the incidence of the slugs during the four years discussed. The data provides a beautiful demonstration of rhythms in numbers and weights as well as the use of field observations both to obtain biological information as well as the need for continuous data, on a statistical basis, before drawing conclusions as to the abundance or otherwise of pests.

The results of weighing the slugs individually has been held over for further study.

In the meantime experiments have been initiated to establish the lapse of time between mating and oviposition and between oviposition and hatching.

The first two Volumes of Dr. Barnes' work on *Gall Midges of Economic Importance* were published in June, 1946. The publication of Volumes 3 and 4 due in autumn of 1946 was delayed by a printer's "go-slow" policy. The final checking of Volumes 5 and 6 approached completion.

C.—Dr. Evans' work on the relations between earthworms and soil fertility has continued with the assistance of W. S. Guild.

Laboratory studies.—The work on the life-cycles of the common species of earthworms is continuing. Many data have been obtained on the following points:

(*a*) incubation periods of the cocoons;
(*b*) number of cocoons produced at different times of the year;
(*c*) number of worms issuing from 1 cocoon;
(*d*) growth period from hatching to sexual maturity;
(*e*) occurrence of parthenogenetic reproduction in certain species. A technique has been devised by which 95 per cent. of the immature worms in field collections can be identified.

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The type of organic matter on which worms feed has a great influence on their rate of reproduction. The droppings of herbivorous animals proved the best source of food, closely followed by peat. Well decayed organic matter such as farmyard manure and sewage sludge was quite unsuitable as was straw, with and without additional inorganic nitrogen.

Field studies.—The numbers of earthworms and the proportions of the different species present on various fields at Rothamsted is determined by the agricultural history of the field. Investigations in the Stirling area of Scotland show that soil type has a big influence on the number and proportions of the different species present. The production of wormcasts in a pasture field was found to be dependent on the activity of 2 species only out of the 7 species present. Fluctuations in soil temperature and moisture largely determine the seasonal activities of earthworms.

Pot culture studies.—The effect of one species of earthworm has been studied in a factorial experiment comparing grass and animal droppings as source of food, and the effect of no added nitrogen against added sulphate of ammonia. The results showed a highly significant effect of worms in increasing the yield of the test plants, mustard, and a highly significant positive interaction between worms and sulphate of ammonia.

D.—Dr. Johnson has done a certain amount of exploratory field work on a method of sampling bean aphis on plants and trapping them in the air.

In connection with possible longer range movement work it is hoped to get two 105-ft. masts from the Air Ministry which can be used for experiments in trapping airborne aphids into a suction trap which is due for delivery early next spring (1947).

A net which is impregnated with a toxic material and which immobilises aphids which are carried on to its surface, as it orientates to the wind, shows promise for short range low level studies.

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BEE DEPARTMENT

By C. G. BUTLER

GENERAL

Both the research and the advisory work of the Department were continued throughout the year. Besides dealing with many enquiries about colony management and the pollination of fruit and seed crops, 1,855 samples of brood and 1,077 samples of adult bees were examined for disease, the results shown in Tables I and II below being obtained.

Various members of the Department gave a number of lectures to Beekeepers' Associations and other organisations, and in addition served on various committees such as the Minister's Bee Disease Advisory Committee, the British Standards Institute Sub-Committee for the standardisation of beekeeping equipment, and the British Beekeepers Association Research Committee.

One member of the Department, Dr. C. G. Butler, toured the U.S.A. and Canada for a few weeks in the spring of 1946 visiting Bee Research Centres, Commercial Beekeepers, and others. A brief account of his visit has been published (113).

Table I.—Brood disease diagnosis, 1st October, 1945—30th September, 1946 (England and Wales)

Disease	*No. of samples*
American Foul Brood (A.F.B.)	1,191
European Foul Brood (E.F.B.)	66
A.F.B.+E.F.B.	0
A.F.B.+Chalk Brood	0
E.F.B.+Chalk Brood	0
Chalk Brood	40
Stone Brood*	1
Addled Brood	48
Chilled, Starved, Neglected Brood	28
No evidence of disease or of abnormal brood; nature of complaint undetermined	481
Total	1,855

* It is of interest to note that this is so far as is known the first case of Stone Brood ever to be definitely diagnosed at Rothamsted.

Table II.—Adult bee disease diagnosis, 1st October, 1945—30th September, 1946 (England and Wales)

Disease	*No. of samples*
Acarine	224
Nosema	16
Amoeba	4
Nosema+Amoeba	0
Paralysis (various types)	253
Arsenical poisoning	3
No evidence of disease or abnormal condition	577
Total	1,077

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Research work

American Foul Brood

Following preliminary experiments in 1944 and 1945 a memorandum on the sulphonamide treatment for American Foul Brood was prepared for the Minister's Bee Disease Advisory Committee. Tests of the treatment on naturally occurring cases of the disease as proposed in the memorandum were carried out at ten selected outside centres during 1946 in collaboration with county beekeeping instructors and bee disease officers. Two of the thirty-two colonies involved in these trials failed to respond satisfactorily to the treatment; one colony reported to be healthy following treatment showed a recurrence of the disease six weeks later; the remaining colonies were all reported to be free from visible signs of disease at the end of the season. Free sulphonamide was found in samples of honey taken from all those colonies which gathered a surplus for extraction whilst treatment was in progress. A detailed report on these trials has been prepared for publication (114). Further trials of the sulphonamide treatment on artificially infected colonies in the Rothamsted Disease Apiary were also carried out. Further trials are planned for the 1947 season.

European Foul Brood

Experiments with sulphonamides against European Foul Brood carried out at Rothamsted on colonies suffering from this disease have given either negative or indefinite results which could not be distinguished from the spontaneous disappearance of this disease which frequently occurs during the course of the season.

A considerable amount of work remains to be done on this disease which appears to be largely confined to certain "E.F.B. Areas" in this country and which appears to be greatly influenced by the balance between bees, brood and stores in the colonies concerned.

Nosema

Tests of the sulphonamides used for the treatment of Foul Brood on bees kept in cages in the laboratory and infected with viable Nosema spores gave negative results in every case.

Pollination

Work has been continued in an endeavour to determine the relative value of honeybees and other insects for the pollination of specific crops. It was found again during 1946 that in the Harpenden district honeybees were responsible for the pollination of the greater part of the red clover seed crop.

Development of a technique to cause honeybees to visit and pollinate the flowers of a predetermined crop such as red clover has been continued. Promising results have been obtained in small scale experiments but it is now clear that further work on the behaviour of bees when seeking nectar and pollen in the field and upon the division of labour amongst bees of foraging age will be necessary before full advantage can be taken of this technique. Recent work by von Frisch suggests that bees can not only indicate to one another the floral source of a particular nectar (or pollen) but also the approximate direction in which the source lies relative

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to the hive and the distance of the source from the latter. This work, if confirmed by experiments planned for 1947, will clearly have considerable bearing upon the conditioning of bees to visit the flowers of a particular crop for purposes of pollination, and may very well lead to more positive and accurate results being obtained in the field in the future. This line of work clearly is full of promise and may lead in a few years to the elaboration of a technique by means of which seed growers will, given suitable weather conditions during the flowering period, be able to ensure a full set of seed of such crops as Red Clovers, White Clovers, Sainfoin, Lucerne, etc.

Studies of the kinds and amounts of pollens collected by honeybees have been continued. It was found that during 1946 each of two colonies of bees in the Home Apiary collected about 12lb. of pollen composed of loads from about 130 different species of plants, but 95 per cent. of all this pollen came from about 20 plant species of which the clovers alone yielded almost 50 per cent. It was further found that such forest trees as Ash, Birch and Oak, which have hitherto been considered doubtful sources of pollen for honeybees, are of considerable importance. A paper on this subject has been prepared (115).

Poisoning by D.D.T. and Gammexane

Work on the possible dangers of sprays and dusts containing D.D.T. and Gammexane to honeybees and other valuable pollinating insects has been completed in collaboration with members of the Insecticide Department. The results show that even when sprays and dusts containing D.D.T. are applied to open blossom the damage to honeybees, bumblebees and species of *Andrena* is negligible, nor is any apparent damage caused to their larvae. Gammexane on the other hand is extremely toxic to all these beneficial insects, and if applied to open blossom in the field may lead to serious consequences. A paper on this subject is being prepared.

The feeding of bees

The series of comparative trials of methods of feeding bees in autumn, winter and spring, and on colony development in spring, carried on each season since 1939 have now been concluded and a paper giving the results published (111). It has been shown that no benefit results from either winter or spring feeding if the colonies are provided with adequate stores of food in the autumn.

Electrical heating of beehives

Further studies on the possible beneficial effects of electrical heating of beehives, using an improved type of frame-heater designed by Mr. E. B. Wedmore, have been carried out in collaboration with the Electrical Research Association. No beneficial results were obtained at any of the intensities of heat employed (112).

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DEPARTMENT OF INSECTICIDES AND FUNGICIDES

By F. TATTERSFIELD

During 1946 Dr. Potter was invited as a visiting professor for a year's stay in the United States by the Rhode Island Agricultural Research Station. He left England at the end of December and has spent nine months at Rhode Island and three months at the Agricultural Research Station, Connecticut. At the end of his stay he paid flying visits to other stations in the United States and in Canada.

For the purpose of this report the work has been divided into chemical and biological sections, but throughout it has been closely interlocked and mutual help has been given.

CHEMICAL WORK

The evaluation of pyrethrum flowers

This problem was raised in different ways during the year. In conjunction with the Imperial Institute we were called upon by the Kenya Pyrethrum Growers Association to recommend methods for the chemical evaluation of pyrethrum flowers.

In 1944–45 collaboration of this department with the Imperial Institute, Dr. S. H. Harper and Messrs. Stafford Allen had resulted in the re-determination of the factor used in determining pyrethrum I by the Wilcoxon method. This work has been drawn together and is ready for publication. The problem now is to draw up a method for applying either this or some other technique for use by analysts, which will give results of reasonable concordance. Discussions with the Imperial Institute and the Scott Laboratory at Nairobi have taken place and Mr. Lord is again cooperating in this difficult task. Preliminary work has already been carried out to ascertain the effect of variations in the technique employed. It is clear that the details will have to be laid down with great particularity if the past recurrent disputes with their resultant losses are to be avoided. During the year we had a conference with the Chairman of the Kenya Pyrethrum Board and with two representatives of the Imperial Institute about to visit the U.S.A. to discuss this matter.

Ryania speciosa

Samples of this plant were received some years ago from Trinidad and not found to have outstanding insecticidal properties. During 1945 fresh samples of root and stem were received *via* the Imperial Institute, Mr. Lord examined them and found that the toxicity of the plant to insects was not of a very high order and was specific in its effects; extracts, however, have a fairly quick knock-down from which insects tend to recover. The plant is worth further examination since it is reported to have specific effects and that the active principle is not easy to extract.

Analogues of D.D.T.

Further work was carried out by Mr. Lord in order to compare the toxicities of D.D.T. analogues. Tests with alkyloxy derivatives showed the ethoxy compound to be the most toxic; beyond this

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toxicity decreased with increase in molecular weight, moreover, the slope of the probit line tended to become less steep. In this work the structure and purity of the various analogues were checked by degradation to the corresponding benzophenones and by estimating the amount of the appropriate halogen acid liberated by the action of caustic soda. Tests were made to ascertain the compatibility of D.D.T. with nicotine; the decomposition observed was studied and found to be catalysed by ferrous and ferric ions and by copper and aluminium ions. Similar tests were carried out with certain alkylamines. A start was made during the year on the effects of these compounds on the respiration of insects, thus obtaining a measure of their metabolic action. Microrespirometers of a modified Barcroft pattern were used, an initial strong stimulus was observed which declined as the series ascended from chlorine upwards. In order of speed of reaction they could be arranged: $F > Cl > Br > I$. Mr. Lord has also carried out some interesting experiments on the sorption of D.D.T. by chitin; it was found to be rapid, but so far no success has been achieved in measuring the rate of penetration.

Gammexane

Using *Oryzaephilus surinamensis* as test subject Mr. Lord compared the insecticidal values of the α, β, γ, and δ isomers of hexahydro-hexachlor-benzene. The γ-isomer was of the same order of toxicity as D.D.T., whereas the α and δ isomers were much less active. The β-derivative was too insoluble to allow of an estimate being made.

The effect of particle size and shape on the insecticidal properties of D.D.T.

Mr. McIntosh, after completing and testing out his dipping apparatus for determining insecticidal potency, has submitted an account of it for publication. Using this technique he has since carried out a long series of experiments in which he has compared the insecticidal values of various suspensions of D.D.T. in which both the particle size and shape were varied. This has involved much work in preparing D.D.T. suspensions of definite types, ranging from the colloidal to relatively large plates and long needles. Such preparations had to be replicable as several repetitions of the toxicity trials had to be made before confidence in the rather unlooked-for results could be felt. Using *Tribolium castaneum*, a relatively robust and easily handled insect test-subject, he showed that within the range of sizes tested toxicity varied directly with average particle size determined by microscopic measurement, but that the shape of the crystals might have a bearing on the results. Thus the order of potency could be expressed as follows: colloid < short plates < large plates < long needles. That the effect was not due to the technique employed was shown by some determinations in which the spraying tower was used and the results shown to hold, when the crystals were small enough to pass through the nozzle intact. The results found an explanation when analyses of the insects for D.D.T., retained on them after dipping, were carried out. This required a very large number of test subjects and the employment of a micro-analytical method. Using a colorimetric technique worked out by Schechter,

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et al., Mr. McIntosh obtained evidence that when his insects were dipped in a colloidal preparation of D.D.T., less of the chemical was retained by the insects than when the long needles were used in the dipping fluid. The difference in amount retained was almost great enough to give a quantitative explanation of the above-mentioned toxicity difference. This finding is of considerable importance and McIntosh proposes to carry the work further with other crystalline insecticides.

BIOLOGICAL WORK

Work has been continued on the rearing of suitable plant insects as test-subjects. These have been needed in large numbers at all times of the year and some ingenuity has been required in securing them. Mrs. Gillham has been mainly concerned with the aphides, *Macrosiphoniella sanborni* and *Macrosiphum solanifolii* and others, while Miss Stoker has had charge of the mandibulate insects, such as the Mustard beetle (*Phaedon cochleariae*) and Diamond back moth (*Plutella maculipennis*) and others. Both have rendered great help in the carrying out of spray trials and in the examination of the results.

Daylight lamps have been in use for rearing purposes and after much delay the new batteries of lamps for comparing the effect on insect resistance, reproductive rate and plant growth due to illuminations of different quality, have been installed and a start made in their use.

Mrs. Gillham has continued the work in which she collaborated with Dr. Potter on the variation in resistance of aphides. The toxicity of various insecticides to aphid test-subjects has been studied over a period of years but a detailed analysis of the collected data has not yet been made.

In general there is a range of variation in resistance, but it seems difficult to correlate this with any particular set of conditions. There are some exceptions showing a greater degree of variation from the rest of the series but it is not known whether any direct environmental effect is involved.

Preliminary experiments with *Macrosiphum pisi* indicate that with this species resistance is influenced by the host plant, insects from clover appeared more resistant to rotenone than those from broad bean or pea.

A laboratory technique for determining the toxicity of stomach poisons

Mr. Way has been engaged for some time in elaborating methods for the valuation of these classes of insecticides. The first stage of the work has been carried to completion and an account is being prepared for publication. Many complexities have been encountered, some inherent in the type of insect used as test-subject or in the chemical compound. Some are of an operational nature. Thus, certain caterpillars fail to feed if confined in too close a space, and some compounds prove repellent or deterrent; in compounds of very considerable toxicity accurate measurement of the very fine deposits required is difficult.

Essentially, the technique should be capable of putting down on foliage very small but evenly distributed deposits, it should afford means of measuring the amount per unit area, and secure the administration of pre-determined doses to individual insects. The

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latter entails keeping the foliage fresh and edible during and after the period of consumption. The assessment of the effects and the statistical analyses of the results follow.

The spraying apparatus consists of a tall cylinder of thin zinc sheet (5 ft. 6 in. tall and 1 ft. 3 in. diam.) which is earthed to prevent charging. The tower is held in a vertical position by adjustable wire braces and rests on a flange surrounding a circular aperture in the top of a stout table. Four tubular vents near the bottom allow for the escape of air displaced by the actual spraying operation, and the top tapers to a duct of 6 in. diam. which leads to the exterior.

Underneath the tower there is a circular spray platform in the table of the same diameter as the tower, with a plate-glass cover constituting a false bottom. Through a hole in the centre of both projects the nozzle of an atomiser. Both spray platform and glass plate can be independently withdrawn in separate slots. Foliage and a weighed sheet of aluminium foil of known area rest on the platform. With the false bottom in position the insecticide is sprayed into the tower and after allowing the larger droplets to fall on the false bottom the latter is removed to permit the mist of insecticide to settle on foliage and foil. By standardising the spraying procedure deposits can be predetermined to within 5 per cent. and the exact deposit per unit area determined by weighing the sheet of aluminium foil.

Known amounts of the sprayed foliage are then fed to insects by appropriate means which have to be adapted to the insect used and the insecticidal purpose under study; for example, if the toxicity to be determined is to be strictly limited to stomach action, then the food has to be administered so that only the mouth parts, at most, come into external contact with the poison. This can be secured by enclosing the insect in a confined channel across the top of which the strip of poisoned leaf is placed; but, as all caterpillars are not amenable to this treatment, a special feeding device is used in such cases; a strip of treated foliage of known area extruding from a small cork clamp, and with the treated surface protected by a celluloid cover, is enclosed with the insect in a small cage. If both external contact and internal effects combined are the subject of study, circles of the poisoned foliage can be enclosed with the insect upon it. The problem of preserving the foliage free from dessication has been a serious one, but devices for maintaining fresh foliage have been designed, and constant temperature and humidity chambers are used for after-treatment storage.

The technique for treating large insect species is highly satisfactory and has been used to determine the effect of insect body-weight on susceptibility to various insecticides. Detailed experiments were carried out using last instar larvae of *Diataraxia oleracea* and *Phlogophora meticulosa*. Results show that D.D.T. and γ-benzene hexachloride are highly toxic but that mature last instar larvae have a much greater resistance than young larvae of the same instar. This difference in resistance with size of larvae is not so noticeable when Lead Arsenate is used as the poison. The size factor in the test subject is shown to be one of great importance and this problem is being made the subject of further study.

The analysis of the results is complicated, the dosage per body weight of the insect has to be determined, entailing weighing large

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numbers of individual insects. The Bliss and Gaddum probit technique is applicable to the statistical analysis of results but the probit plane conception of Finney has to be employed and this adds considerably to the length and complexity of the computations.

The effect of D.D.T. and benzene hexachloride on bees*

This work was undertaken at the instance of a sub-committee of an A.R.C. Conference on insecticides. A joint investigation between this department (M. J. Way) and the Bee department (Miss A. Synge) has involved a considerable amount of work, which was accentuated by the bad weather conditions ruling during the summer and early autumn of 1946. The results obtained were laid before a conference of advisory entomologists in December, 1946, and have been embodied in a report to the A.R.C. Although not yet in a final form the results can be summarised thus:

Laboratory tests under rather drastic conditions showed B.H.C. to be highly toxic to *A. mellifera*. Used as a contact insecticide, with the γ-isomer content well below field concentration, commercial preparations gave 100 per cent. kill. Field concentrations of D.D.T. proved only partially toxic. Tested in the laboratory as *stomach poisons*, using specially prepared suspensions, it was shown that D.D.T. in colloidal form is about four times as toxic as a crystalline preparation. Lead Arsenate *under these conditions* is somewhat less potent than D.D.T. and slow in its effects, but B.H.C. by comparison is very toxic.

Laboratory experiments by contact with D.D.T. and γ-B.H.C. on various bumblebee species showed that workers are similar in their susceptibility to workers of *A. mellifera*. Queens and Drones are more resistant, D.D.T. at high concentrations and under drastic conditions having little effect. This is a matter of some importance since in the spring *Bombus* queens are foraging and their loss means the potential loss of colonies of workers.

Field experiments showed that both *A. mellifera* and *Bombus* workers visiting open blossoms, treated with commercial D.D.T. sprays and dusts, are not appreciably affected. This finding, however, should not be interpreted as justifying the treatment of open blossom with D.D.T., since there is the risk that an activated form of this compound might have serious effects. Preliminary work, which owing to weather conditions and experimental difficulties gave only tentative results, did not indicate D.D.T. to be a serious danger to honeybee larvae. It would thus appear that, used with reasonable care, D.D.T. is safe to bees.

Field experiments with B.H.C. when applied to open blossom showed this insecticide to be highly lethal to bees and to be harmful to them after a period of at least four days. In view of this it presents a danger to visiting bees by chance contacts, even if sprayed before blossom opens. There was no repellency noticeable, and as speed of toxic action is not sufficiently quick to prevent contaminated workers returning to the hive it is considered that the use of B.H.C. might also be dangerous to nurse bees and larvae through contact with contaminated food brought to the hive by the workers.

* The letters B.H.C. are subsequently used for this material.

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Toxicity of D.D.T. and B.H.C. to several parasite and predator insects (M. J. Way)

Foliage was treated with certain commercial preparations of D.D.T. and B.H.C. enclosed in cages with certain parasite or predator insects. Under these conditions it was shown that adults of several hymenopterous aphid parasites and adults of several Syrphid species are very highly susceptible to B.H.C. and are also killed by D.D.T. which, however, is not as toxic as γ-B.H.C. Syrphid larvae are not affected even after drastic treatment with D.D.T. but young larvae are killed by spraying and dusting with field concentrations of B.H.C. Fairly high concentrations of B.H.C. are required to kill mature syrphid larvae. Syrphid larvae are not affected by field concentrations of Derris spray and Nicotine dust and spray.

Batches of Coccinellid eggs were directly treated with certain commercial sprays and dusts of D.D.T., B.H.C., Derris and Nicotine. Results show that in these preparations D.D.T. and B.H.C. have apparently no ovicidal action but larvae are destroyed by B.H.C. after emergence. D.D.T. appears to cause little harm to emerging larvae. Derris has a powerful ovicidal action even at low concentrations while Nicotine spray shows no harmful effects.

Effect of D.D.T. and B.H.C. on vegetables and fruit crops (Miss R. I. Stoker)

The phytotoxicity of these insecticides has been studied and the possible tainting effect of B.H.C. examined. The decline in yield of tomato after treatment with D.D.T. has not been confirmed, nor have the distorting effects on cucumbers been repeated.

Small scale field experiments with several commercial preparations of B.H.C. were carried out on the following seedling vegetables: radishes, turnips, swedes, spinach, beetroot, peas, carrots, onions. The results of preliminary trials were:—

"Gammexane" Dispersible Powder	0·2%	isomer	—radishes, turnips, swedes, spinach, beetroot; scorched
,, ,, ,,	0·04%	,,	—turnips and radishes slightly scorched
,, General Purpose Dust	0·5%	,,	—slight evanescent retarding on radishes
,, Flea Beetle Dust	0·2%	,,	—only applied to turnips and swedes with no marked effect

A field experiment on kale seedlings showed that sprays (Dispersible Powder) containing concentrations of less than 0·1 per cent. of the γ-isomer of B.H.C. could be used with safety.

It can be concluded from all these experiments that, following application of commercial sprays containing above 0·1 per cent. γ-isomer, brassica seedlings, beetroot and spinach are liable to damage and that there is some risk of retardation of growth and possibly germination by the use of both the General Purposes and the Flea Beetle B.H.C. dusts on brassicas.

Comparison of the effect of B.H.C. and D.D.T. on tomatoes (variety, Harbinger)

A carefully devised pot experiment in the open, in which was used Guesarol E spray (0·2 per cent. D.D.T.), B.H.C. Dispersible Powder at 0·01 and Liquid Agrocide at 0·015, 0·0075, 0·0037 per

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cent. γ-isomer showed that these preparations had no direct toxic effects.

The effect of B.H.C. on the flavour of vegetable crops

Small rows of various vegetables were sprayed with a Mysto sprayer in such a way as to prevent much spray reaching the soil. The following are the results, concentrations being in terms of the γ-isomer:—

Peas.—Sprayed in flower (Dispersible Powder). Tainting at 0·1 and 0·05% particularly after cooking.

Carrot.—Young plants dusted (General Purpose Dust) and sprayed (Dispersible Powder). Tainting to young and fully matured carrots with 0·2% and 0·1% spray and 0·5% dust. Lower concentrations gave no taint.

Beetroot.—As for peas. 0·1% Dispersible Powder caused loss of flavour, lower concentrations did not.

Onion.—As for peas. No taint.

Marrow.—Liquid Agrocide 0·15–0·05%
Dispersible Powder 0·1–0·01% } All treatments imparted an earthy flavour.

Cauliflower.—Dispersible Powder 0·01–0·05%. Earthy flavour.

Lettuce.—As for peas. 0·1% caused a bitter taste. No taint at lower concentration.

Radishes.—Dispersible Powder 0·2 and 0·04%. No taint.

The insecticidal properties of film deposits of D.D.T. and B.H.C.

Dr. Pradhan, a Government of India State Scholar, has carried out investigations on these problems since his arrival in February, 1946. Since the potencies of D.D.T. and B.H.C. are relatively long-lasting, the effects of films laid down are likely to prove of practical importance. Dr. Pradhan has been engaged in developing appropriate laboratory techniques for studying them. Insect test subjects selected have been *Tribolium castaneum*, *Plutella maculipennis*, *Macrosiphoniella sanborni*, the first mentioned insect is being used as it is far easier to confine it on a film than most plant-feeding insects. Some difficulty has been experienced in the case of B.H.C. in separating the fumigant from the direct contact action, but this has been partially achieved.

Effect of type of surface on toxicity

Preliminary experiments have been carried out to test the effects of the following: wax, filter paper, bolting silk, leaves of water lily, marrow, cabbage and geum in order to cover a relatively wide range. It is clear that the effectiveness of D.D.T. will depend on the surface upon which it is deposited. The effect of temperature upon the toxicity and speed of reaction of D.D.T. films is being studied.

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FIELD EXPERIMENTS ON THE ROTHAMSTED FARM

The following members of the staff, who constitute the Field Plots Executive Committee, are responsible for planning and carrying out the programme of field experiments: E. M. Crowther, H. V. Garner, J. R. Moffatt, D. J. Watson and F. Yates.

The programme of experiments was slightly smaller than in previous years. The total number of experimental plots was 1,554, compared with 1,722 in 1945.

A.—Classical experiments

1. *Broadbalk and Hoosfield.*—Some of the Broadbalk plots and the whole of Hoosfield were heavily infested with wild-oats. An attempt was made to remove them by hand-pulling soon after the panicles emerged. All the Broadbalk wheat plots were cleared, except for Section IV of plot 2, where the infestation was particularly heavy, and had obviously depressed the growth of wheat. On this section a narrow strip was cleared of oats and left to give an estimate of yield at harvest; the rest of the crop was cut green and carted off to prevent reinfestation with shed seed.

The infestation on the Hoosfield barley experiment was more severe and widespread than on Broadbalk, and it was found impossible to clean more than a small fraction of each plot by hand. Accordingly the weeding operations were restricted to a small section of each plot. The crop on these parts was left to ripen, and the unweeded crop was cut green and removed.

2. *Barnfield.*—Sugar beet were grown on Barnfield for five years before the present continuous cropping with mangolds began in 1876, but at that time the crop was not commonly grown in this country and the results were of little practical interest. As it has now become one of the most important crops in the Eastern Counties it was decided to resume cropping with sugar beet on about a quarter of each plot, the remainder continuing in mangolds as previously. It is hoped that this will provide useful information on nutrient-deficiency symptoms in sugar-beet, and on the effect on yield of nutrient supply over a much wider range than can be obtained in short-period experiments on other fields of the farm.

Unfortunately, the 1946 crop was very irregular, and failed almost completely in some parts of the field. It was thought that this might be due to an increase in the severity of attack by beet eelworm, which is known to be present in the field, and arrangements were made for a further investigation of the eelworm cyst population after the removal of the crop.

No changes were made in the other classical experiments.

B.—Modern long-period experiments

All the existing long-period experiments were continued, and no new ones were begun. The deep-cultivation rotation experiment, started in 1944, has passed through its preliminary years, and all stages of the rotation were established for the first time in 1946.

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C.—Short-period experiments

Short-period experiments were made on the following problems:

(1) *Bulky organic manures.*—The manurial value of the following materials was tested: farmyard manures, made with varying ratios of straw to feeding-stuffs, in covered boxes or in open yards; sewage sludge; composts made of straw and sewage sludge; bracken compost; peat. To distinguish between physical and nutrient effects of the organic manures, the responses to nitrogen, phosphate and potash in the presence and in the absence of the manures were measured.

The residual effects of similar materials applied to potatoes in 1945 were measured in a wheat crop.

(2) *Fertiliser placement.*—Work on fertiliser placement which has been going on for several seasons was continued. Two experiments were made. The first, on potatoes, compared the effect of a broadcast application of mixed fertiliser with applications in bands in contact with the seed, below the seed, or on either side of the seed. In the second, the effects on winter beans of phosphate and of potash broadcast or drilled with the seed were measured.

(3) *Beans.*—The experiment on beans tested, in addition to the placement of phosphate and potash, the responses to farmyard manure and nitrogen. A comparison of early and late autumn sowing was also included, but the late sowing failed because of severe damage by birds and had to be resown in spring.

In another experiment four strains of winter beans were compared. Two rates and times of sowing and two methods of sowing, by broadcasting the seed before ploughing or dropping it into the plough furrows, were also tested.

(4) *Eyespot disease of wheat.*—An experiment started in 1944, on varietal differences in susceptibility to infection with eyespot disease and to lodging, in crops sown in October or in November, was continued.

In another experiment the effects of varying the rate and depth of sowing, and the rate of application of a nitrogenous top-dressing on the amount of infection and lodging, were studied. This experiment also included a test of spraying with sulphuric acid in the spring as a method of controlling the disease.

(5) *Potatoes.*—The study of the effect of varying the time of planting between the end of March and early June on yield and on the responses to farmyard manure and fertilisers, begun in 1945, was continued in an experiment which was also used to provide information on the spread of leaf-roll and severe mosaic virus diseases from infected tubers planted on each plot.

Another experiment was designed to compare deep and shallow inter-row cultivation, and to measure the effects of earthing up and of a straw mulch applied between the rows, on yield and on the amount of greening and blight infection in the tubers.

Hoos field four course rotation

This experiment was started in 1930 on a four course rotation with one block for each crop each year. Each block had 25 plots and different experimental manurial treatments were given to five plots in any one year and repeated on the same plots every fifth year. The combination of a four course cropping rotation with a five

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course manuring rotation means that for each material the combination of a given crop and a given stage of exhaustion recurs only once in 20 years. By this time each one of the 20 plots for each manure will have been used to test each stage of exhaustion on every crop. The effects of soil irregularities will thus be reduced to a minimum.

The experiment falls into two sections. The first tests three bulky organic manures: farmyard manure, straw-compost, and raw straw. The farmyard manure and straw compost supply equal amounts of organic matter, and the raw straw is equal in amount to that used in making the compost. Each manure is analysed shortly before application, and extra fertilisers are added to provide equal amounts of nitrogen, phosphoric acid and potash in all three treatments. No further fertiliser is given in the next four seasons. The second section has two treatments—superphosphate and mineral phosphate—applied once in five years with the same total amount of phosphoric acid as in the adjusted organic manures, but with annual applications of nitrogen and potash equal to one-fifth of the total amounts used in the organic manure series. The superphosphate series thus tests five-yearly phosphate with annual nitrogen and potash against equal total amounts of plant foods in organic manures applied every five years. The experiment would show in time whether the omission of organic manures has any cumulative effect. Mineral phosphate is known to be unsuited for this neutral soil, but it was included to serve as a "control" in the early years and also to test whether or not it might exert any progressively beneficial effect over a long period.

Data for each stage of exhaustion are already available in fourteen seasons for potatoes, barley and wheat and in ten seasons only for rye grass. A summary of the main results is given below.

Residual effects in Hoos Field four-course rotation experiment, Rothamsted, 1932 to 1945

The dung and straw compost each supplied 50 cwt. organic matter per acre. The raw straw equalled the amount used to make the compost. Fertilisers were added to raise the total plant food to 1·8 cwt. N, 1·2 cwt. P_2O_5 and 3·0 cwt. K_2O per acre. These manures were applied every five years with nothing in the four intervening seasons.

The superphosphate and mineral phosphate supplied 1·2 cwt. P_2O_5 per acre every fifth year with 0·36 cwt. N and 0·6 cwt. K_2O as sulphate of ammonia and muriate of potash per acre every year.

The benefits from farmyard manure are very much less after one year than in the year of application, and there is a small but steady decline up to four years after application. In the year of application raw straw with fertilisers gave better results than farmyard manure or straw composts, the advantage being especially great with rye-grass, which responded very well to the large amount of sulphate of ammonia given with the straw. The average residual effects from raw straw with fertilisers were at least equal to those from farmyard manure. Farmyard manure gave better results than straw-compost on potatoes, both immediately and as residues; these two manures gave equal yields for the other crops. Raw straw with fertilisers gave better results than straw-compost,

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	Years after application	Potatoes tons per acre	Barley cwt. grain per acre	Rye grass cwt. dry matter per acre	Wheat cwt. grain per acre	Average crop* cwt. per acre
Farmyard Manure						
	0	5·93	28·5	18·9	22·6	24·9
	1	4·71	23·2	12·5	18·9	19·5
	2	4·56	20·7	10·3	17·4	17·8
	3	4·29	19·2	9·6	17·2	16·9
	4	4·06	18·5	8·9	16·0	15·9
	Mean	4·71	22·0	12·0	18·4	19·0
Straw Compost						
	0	5·30	27·7	18·1	23·2	23·9
	1	4·16	22·2	12·9	18·3	18·6
	2	3·86	20·2	9·8	16·8	16·5
	3	3·72	19·2	8·9	17·5	16·0
	4	3·73	18·3	9·7	15·6	15·6
	Mean	4·15	21·5	11·9	18·3	18·1
Raw Straw						
	0	6·42	29·5	30·6	25·3	29·4
	1	4·70	22·5	12·4	18·0	19·1
	2	4·77	21·0	11·9	18·7	18·9
	3	4·32	20·6	10·8	17·6	17·6
	4	4·18	20·8	9·4	16·6	16·9
	Mean	4·88	22·9	15·0	19·2	20·4
Superphosphate						
	0	6·44	28·4	18·1	20·3	24·8
	1	5·16	27·2	19·4	20·3	23·2
	2	5·36	27·1	18·8	20·3	23·2
	3	5·38	27·1	16·8	20·5	22·8
	4	5·08	26·7	17·2	20·3	22·4
	Mean	5·48	27·3	18·1	20·3	23·3
Mineral Phosphate						
	0	4·17	24·1	16·4	19·6	20·2
	1	4·17	25·0	16·8	20·4	20·8
	2	4·24	25·6	15·8	20·3	20·7
	3	4·54	23·8	15·6	21·0	20·8
	4	4·12	26·2	16·2	19·8	20·7
	Mean	4·25	24·9	16·2	20·2	20·6

though the differences in residual effects were small for cereals and rye-grass.

The plots with superphosphate every five years and one-fifth of the total nitrogen and potash given each year gave yields similar to farmyard manure in the year of application. This suggests that only about one-fifth of the nitrogen in farmyard manure is immediately available. In residual effects these fertiliser plots were far superior to the residues of farmyard manure at all stages, because the annual application of nitrogen and potash supplied much more available plant food than the residues from the organic manures.

The superphosphate plots brought out a most important general point in connection with the residual value of fertilisers. The yield of potatoes immediately after application was over 1 ton per acre more than from residues at any stage, but the value of the residues fell off only very slowly, if at all, from the first to the fifth year. Since mineral phosphate gave the same immediate and residual effects it may be assumed that this form of phosphate has so far been practically ineffective. If mineral phosphate is treated as a "control", it follows that superphosphate has a considerable and

* Approximately in terms of dry matter on basis 1 ton potatoes = 5 cwt. grain.

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prolonged residual effect, since its residues give one ton more potatoes per acre than the residues of mineral phosphate for each of the five years.

A similar effect is also seen in barley. The figures are:—

Difference superphosphate—rock phosphate

	1st Year	2nd Year	3rd Year	4th Year	5th Year	Mean
Potatoes, tons ...	2·27	0·99	1·12	0·84	0·96	1·24
Barley, cwt. ...	4·3	2·2	1·5	3·3	0·5	2·4

The high immediate effect of superphosphate on potatoes clearly depends in part on the circumstance that it is applied in bouts at the time and in the place where it can act most quickly on the young crop. This is an excellent form of "fertiliser placement". All residues from previous crops are necessarily much less efficient, because the intervening ploughing dissipates them through a large mass of soil and leaves no local concentration near the sets. This result must be expected in all soils, but in many there is the additional rapid wastage through so-called "phosphate fixation" or the formation of inert and useless residues in the soil.

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THE FARM

By J. R. MOFFATT

The area farmed during 1946 was 501¾ acres, of which 324¾ acres were under arable crops (including leys). The main crops grown were wheat, 59 acres; barley, 70 acres; oats, 17 acres; potatoes, 27 acres; beans, 11 acres; with smaller areas of sugarbeet, kale, mangolds and rye. The area under temporary leys was 114 acres. During the year some 20 acres of permanent grassland were ploughed up.

Compared with 1945 these figures show a slight reduction in the tillage area while the area under temporary leys increased from 84 to 114 acres. The wheat acreage dropped but that under barley rose considerably, while the area devoted to other crops remained at about its war-time level.

Conditions in the autumn of 1945 were very favourable to farm work. All ploughing and winter corn sowing was carried out under excellent conditions, while root crops were lifted and carted without difficulty. Early in 1946, however, there was a spell of about 11 weeks during which very little land work was possible because of frost, rain and snow. The preparation of spring seed beds and the sowing of the crops was seriously delayed. During this spell about 20 acres of old grassland were broken up, the potatoes in the barn were sorted, and threshing was completed. Average grain yields from the 1945 crops, per acre, over the whole farm, including experiments, were as follows: wheat, 25·1 cwt.; barley, 21·2 cwt.; oats, 27·75 cwt.

A dry spell in March and April eventually enabled all spring crops to be sown under good conditions although rather late in some cases. The cutting and saving of the hay crop was considerably delayed by damp and cold weather in June, in which month there were 21 wet days, with a rainfall of 2·66 in., while sunshine figures were 50 hours below normal. Most of the hay-making, therefore, had to be done in July, when the crop was past its best, but it was carted in satisfactory condition.

The weather during the corn harvest was disastrous. This very protracted and disheartening operation commenced late in July and continued into October. Rain fell on 39 days in August and September, and totalled 7·82 in., compared with the average of 4·93 in. Most of the experimental crops were carted early and suffered little or no damage, but the consequent delay in harvesting the non-experimental areas caused heavy losses in both quality and quantity, which will be reflected in the financial returns. The wheat stood well, but most of the barley and oats were lodged, some so badly that we had to resort to scything. Most of the crops sprouted either before cutting or while in the stook, and the value of the corn was thus considerably reduced. The yields, however, proved to be above expectations. The average yields per acre for 1946 over the whole farm were: wheat, 28·13 cwt.; barley, 20·9 cwt.; oats, 21·3 cwt.; and beans, 18 cwt. The high wheat yields were due primarily to the fact that the short stiff-strawed varieties were grown and given liberal dressings of sulphate of ammonia.

The protracted harvest seriously upset the autumn schedule of work. The threshing of the outside corn stacks and the ploughing

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for winter corn, which normally take place between harvest and potato lifting, could not be done. But fortunately a fine spell of weather in October, 1946, enabled the potatoes to be lifted under almost ideal conditions; the tubers came out clean and dry, and most were stored in large heaps in the barn. The crop was attacked by Late Blight about mid-September, and although the tops were burnt off some tubers were affected.

Sugar-beet lifting followed almost immediately. This was the only crop that did not appear to have suffered from the unfavourable weather conditions. There was a bigger proportion than usual of bolters, but roots and tops grew well throughout the season. The average yield per acre was 15 tons of washed beet, with a sugar content of 15·2 per cent. Weather conditions for root lifting were atrocious, the land being either a sea of mud or frozen hard. This operation, which normally finishes early in December, was not completed in 1946 until 31st December.

The growth of the mangolds on the classical field (Barnfield) was uneven and yields were low. This was probably due to the sugar-beet eelworm, which is prevalent over the whole field, and which seems to be making its presence felt very severely. Soil samples have been taken to measure the intensity of the infestation, and a decision regarding the future of the field will be made when the eelworm counts are known.

The late corn harvest which delayed the harvesting of the potato crop in turn delayed the start of the winter corn sowing. Unfortunately, November was a very wet month, with rain falling on 23 days and a total fall of well over twice the average. This considerably hampered the drilling of winter corn, and drilling operations had to be abandoned with little more than half the scheduled wheat acreage sown. However, the variety used mainly, Bersee, gives very satisfactory yields when sown in early spring, so that the seed not used will be sown in the spring of 1947 if weather conditions are suitable.

Use of herbicides

Field-scale tests of herbicides were continued, and were extended to cover a wide range of materials. Much useful knowledge was obtained. A trial was also made using sodium chlorate at 1½ cwt. per acre on ploughed land in the late autumn of 1945, to eradicate twitch (*Agropyrum repens*). The twitch was almost completely eradicated, and the absence of annual weeds in the sprayed areas was very noticeable. The surrounding unsprayed areas were badly infested with black bent (*Alopecurus agrestis*), with some wild oats (*Avena* spp.), but these two noxious weeds of arable land were completely absent from the sprayed plots. The germination and growth of the barley, sown in the spring of 1946, was in no way affected, and in fact the crop on the sprayed areas appeared much stronger throughout the season. A further very noticeable fact was that while much of the unsprayed barley was lodged, little or no lodging occurred on the sprayed plots. Annual weeds made their appearance on the sprayed plots soon after harvest, but even then the stubble was much cleaner than that of the untreated areas. Observations in the spring of 1947 showed that the areas treated with sodium chlorate in 1945 were almost clear of twitch, while there were fewer annual weeds than on the untreated areas.

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Storage of potatoes under cover

Following upon tests made with Majestic tubers in previous years to determine to what depths potatoes could be stored under cover, a test was made in a Dutch barn in 1945–46 with a heap measuring 21 ft. by 24 ft., with a height of 9 ft. against the front straw bale wall, and sloping up to 12 ft. deep in the middle of the heap. On this area of 56 square yards there was approximately 100 tons of potatoes. The tubers were free from blight and reasonably clean and dry when stored. No ventilation was provided, yet when the potatoes were sorted in March and April, 1946, the tubers were in perfect condition. There was an initial rise in temperature of 4·7° C. followed by a steady fall until the end of January, and thereafter the temperature in the heap followed, after a considerable time lag, the variations in the air temperature.

Livestock

The cattle breeding policy was again governed by the necessity to produce an even bunch of young stock of known history for grazing experiments. The 23 Blue-grey and Kerry cows, now 10 years old, were bulled by an Aberdeen-Angus bull and produced their last lot of calves in 1946. There is now sufficient of their progeny on the farm to stock the main grazing experiment until its conclusion. The cows reared only their own calves, as the aim of the breeding policy would have been defeated had bought-in calves, no matter how suitable they may have appeared, been available for fostering on. The cows remained outside for most of the year, only being brought into the yards for part of the winter to tread straw into dung. They calved outside in the spring, the calves being weaned into covered yards late in the following autumn. The feeding of concentrated foods was restricted to the short time the cows were yarded, and then the ration consisted almost entirely of home-produced foods.

The Half-bred breeding flock of ewes was retained, although the numbers put to the Oxford rams were reduced by culling to 130. Time of lambing was set back so that grass should be avilable for the ewes soon after lambing. The lambing season was quite successful, 215 lambs being tailed from 130 ewes put to the tup, giving a percentage of 165. There were four barren ewes. The use of purchased feeding stuffs was almost eliminated, being restricted to the small proportion of protein-rich food required to balance the home-grown foods.

Conclusion

In retrospect, the year 1946 does not now appear so unsatisfactory as it did at the time. The unprecedently bad corn harvest conditions, the difficulty in harvesting the sugarbeet and mangold crops and in drilling the winter corn seemed to cast a cloud over the whole year's work. Yields of all crops were up to, or above, average, and the experimental crops suffered little or no damage by the weather. The damage to the non-experimental crops was much lighter than anticipated, and yields much higher. Root crops generally benefited from the heavy rains and gave satisfactory yields. There was an abundance of grass throughout the year, and both cattle and sheep thrived on it.

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WOBURN EXPERIMENTAL FARM

The season 1945–46 was a difficult one. After a mild but wet winter there followed a dry spring and a very wet summer with many thunderstorms. This rendered cultivations difficult, encouraged weeds, and lodged much of the corn. It was a very troublesome harvest. In August and September there was 6·5 in. of rain and 38 rainy days. Consequently most of the grain was not secured in the best condition. Potatoes were attacked by blight, though the experimental crops escaped entirely. Sugar beet grew well, but the sugar content was lower than usual.

Field experiments

1. *Continuous wheat and barley experiments*

The present interest of these experiments lies in the effect of the manuring for the 50 years 1877–1926 on the fertility of the land under various further treatments. The effect of fallowing in restoring the fertility of this exhausted land was tested over two five-year periods, and since 1943 the effect of nitrochalk has been studied. In 1946 the wheat results were vitiated by rabbit damage and by the weed *Holcus mollis*, which increased to such an extent that the yields were not recorded. The barley results were more reliable, though they were affected by the development of wild oats during the last five seasons, which, although observed on the plots for at least 40 years, had never before become a serious pest. A preliminary examination of the barley yields indicate that the effect of nitrochalk has been very much greater in plots formerly receiving phosphate and potash than on those without mineral manures. The action of nitrochalk on the farmyard manure plots has been about the same as on those treated previously with mineral manures only. The figures need further analysis and the matter is in hand.

2. *The maintenance of the fertility of light land*

One of the purposes of the Woburn Station is to determine the best methods of maintaining the fertility of light land, especially at the present time when the amount of available farmyard manure is becoming less. This is the basis of the following three long-term experiments.

(a) *Alternate husbandry experiment.*—In recent years it has been contended that the best way of maintaining the fertility of land is to have an alternation of ley crops such as grass and clover or lucerne occupying the land for several years, followed by arable crops to utilise the accumulated fertility. . How far this is more effective than a well planned arable rotation with proper use of fertilisers and small amounts of farmyard manure or compost has been tested at Woburn since 1938. The rotations compared are:—

(i) Three years' ley, grazed.
(ii) Three years' lucerne, cut for hay.
(iii) Potatoes, wheat, and one year ley, cut for hay.
(iv) Potatoes, wheat, kale.

Followed in each case by testing crops of potatoes and barley. As difficulty had occurred repeatedly with the kale crop it was decided

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to replace this in 1946 with sugar beet. A similar amount of phosphates and potash is given in each case, but the amount of nitrogenous manure varies, being adapted to the crop. All the plots are divided, one half receiving 15 tons of farmyard manure per acre applied to the first test crop of potatoes.

We have now nine years' results from this experiment, giving five testing crops of potatoes and four of barley. The general results obtained are in very much the same direction as previously and may be stated as follows: (*a*) The potato crop following the three years' ley or the lucerne is definitely bigger than after the continuous arable rotation, but the second crop (barley) shows no significant advantage; (*b*) the effectiveness of a moderate dressing of farmyard manure for the potatoes following the grazed ley is much less than after either a lucerne ley hayed every year, or continuous arable cropping. The experiment is being continued and forms one of the most interesting areas of the farm.

(b) *Six course experiment with fertilisers only.*—This experiment, which has been carried on since 1930, receives no organic manures, but has varying amounts of nitrogen (in the form of sulphate of ammonia), potash (in the form of muriate of potash), and phosphoric acid (in the form of superphosphate) for each crop. The rotation consists of barley, clover, wheat, potatoes, rye, and sugar beet. It has been decided recently that the results should be worked up immediately, and it is hoped that the publication of these will be made during the coming year. One result is clear. There has been so far no indication of any general deterioration of the crops as a result of using fertilisers alone, though the crops of potatoes and sugar beet in 1946 were smaller than usual. On the land at Woburn there is no advantage in using superphosphate, and very rarely in using potash manures; while sulphate of ammonia usually gives very considerable increases with all crops except clover.

(c) *Green manuring experiment.*—The use of green manures for the maintenance of fertility has often been recommended, and experiments on the subject, using mustard and tares as green manures, have been in progress at Woburn since 1893. The present experiment, laid out in 1936, compares the effect on kale followed by barley of the following treatments: (1) two green manures grown in winter and spring, (2) ryegrass and clover undersown in the previous barley crop, (3) bare fallows. The green manures are ploughed-in about June. The technical difficulties of such an experiment are great, and the kale crop has so often failed that it was decided to replace it by a transplanted crop of winter cabbages of which the first crop was grown in 1946. Till 1945, inclusive, the green manures used were mustard and tares, but it was then decided to replace the mustard by rape sown where possible in the autumn, and the tares by lupins (for which crop the Woburn soil is specially suitable) sown in the spring. Additional variants in the experiment are the addition of straw to half the plots and of farmyard manure also to half of the plots.

So far as the experiment has gone it is clear that the crop of kale or its equivalent is smallest after the ryegrass, and that there has been little difference between the effects of the other green crops, of which clover is probably the best. In the case of the

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second crop, barley, there has been little effect of any of the green manuring crops. Straw has uniformly reduced the kale crop.

3. *The making of a market garden soil*

In the year 1942 an experiment was undertaken to determine the relative value of farmyard manure, vegetable compost, sewage sludge, and a compost made from sewage sludge and straw, in converting a very exhausted area of the Woburn farm into land capable of growing market garden crops. The organic manures were also compared with fertilisers alone. The area chosen was one which was exceedingly poor, but which, by its character and texture, should make a good market garden soil, and each of the above materials was applied yearly at 15 and 30 tons per acre. A two-year rotation of vegetables was adopted, namely, first year: early green peas, followed by leeks; second year: globe beetroot followed by winter cabbage. The actual crops were only a measure of the condition of the soil and the interest of the experiment is rather in the change in the soil than in the nature of the crops. The year 1946 was the fifth year of the experiment.

The results are not yet ready for analysis, but it is clear that the effect of the different organic manures is distinct and that they differ according to the crop used. The fertilisers without the organic manures are clearly inferior.

4. *Experiment on take-all disease of wheat and barley*

In connection with the work on this very destructive disease of cereals, and especially of wheat and barley, conducted by Dr. S. D. Garrett at Rothamsted, an experiment was laid out at Woburn in 1943 to test several methods of counteracting the disease. The experiment, which will be fully reported on by Dr. Garrett, compares the amount of disease in a barley crop after early ploughing as against late ploughing, after an under-sown crop of trefoil as against keeping the land bare during the previous winter, and after early and late treatment with a nitrogenous fertiliser (sulphate of ammonia in this case). The crop in 1946 is the last of the series.

One result is the remarkable effect of the undersown trefoil on the barley in which it is grown, for in every case in 1946 the yield was very significantly greater than in the corresponding plots without trefoil.

5. *Other field experiments*

For a number of years the Woburn farm has taken a share in the study of certain foreign crops which it was thought might be suitable for cultivation in this country. For instance, we have now a type of soya bean which, after an experience of fifteen years, can be relied on to ripen in this part of England. Though it is a dwarf type it can, in good soil, produce about 11 cwt. of dry beans per acre. Even in a wet autumn like 1946 the crop has ripened without difficulty. The question has been to see whether this yield could be increased, especially since it was found that a dwarf type like this can be grown much closer than is usual, and there is no doubt that by this means the yield can be stepped up to a considerable extent. Other suggested varieties have been tested but none has so far been

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found which will ripen as early and give as good a yield, while most of the seeds imported directly from America have been found to be infected with a virus disease which, under the difficult ripening conditions of England, have ruined the crop. This is a danger which has not been realised by most of those who have attempted to grow soya beans in England from foreign seed.

Experiments have again been made in 1946 with the type of early maize which, while giving good cobs for eating, yet will ripen seed satisfactorily in this part of England. Even in the wet and cold autumn of 1946 a good yield of seed was obtained.

We also tried again two varieties of sweet lupins with the intention of seeing how late in the season they could be sown so as to give a fodder crop late in the autumn. Under the conditions of 1946 it was found that both yellow and blue sweet lupins sown at the beginning of August were not suitable for this purpose. The yellow variety gave more growth than the blue, but neither produced a useful crop in the wet autumn of this year.

Pot experiments

The pot culture station at Woburn is the oldest experimental pot station in Britain, and it has been used for carrying out special investigations which could not be done in the field. Four different subjects are being investigated in 1946.

1. *Clover sickness*

In a paper published in 1938 it was shown that clover sickness is not necessarily connected with the presence of eelworms in the soil or with any recognised fungus attack. On the other hand, soil which has become clover sick by growing many crops of clover in succession can be made to grow healthy crops of clover by heating (moist) to a temperature of 70° F. for two hours, and also by adding to the soil a large dose of farmyard manure. Confirmation of these points has now been obtained. It has also been shown that healthy soil cannot be inoculated with the sickness, that washing of the soil with water makes very little difference to its virulence, that the washing water from the soil does not cause the disease in healthy soil, and that while dressings of charcoal reduce considerably the affection in a clover sick soil, the addition of colloid matter to the soil had no beneficial effect. The results have now been put together and are being offered for publication in the very near future.

Attempts are also being made to see how the advent of clover sickness in soil can be hastened. In 1946 certain factors on the onset of infection have been studied, namely the effect of temperature, of partial water-logging of the soil, or of an increase of the proportion of clover to soil. The results cannot be determined till a testing crop is grown in 1947, but this test will certainly be made in the coming year.

2. *Competition of crop plants and certain weeds*

The study of the competition of barley and certain weeds under controlled conditions has continued. A paper on the competition between one of the forms of twitch common at Woburn (*Holcus mollis*) is now in the press and will come out in the "Annals of Applied Biology" in 1947. In the last year a similar study of the

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competition between barley and chickweed (*Stellaria media*) has been conducted, and the results are now being worked up.

3. *The nutrition of barley under very acid soil conditions*

This study, which has now continued for a number of years and in connection with which two papers have already been published, has been continued in an attempt to find out why barley will not grow under conditions more acid than that represented by a pH value of 4·7 to 5·0. This year for the first time we have succeeded in getting a healthy crop of barley at a pH value of 4·3, by large additions of a soluble phosphate to the soil coupled with a small addition of calcium nitrate. Increase in the colloid contents of the soil by the addition of bentonite made very little difference to the growth. Other points have come out of this intensive study, and the whole of the work to date is now being worked up for publication.

4. *How far is a growing plant efficient as a user of the nitrogen in the soil?*

This is a matter which has been under investigation in the last three years, using barley as the test plant. It is a continuation of work done for a number of years on the effect of green manures as sources of nitrogen and what happens to their nitrogen when they are buried in the soil.

STAFF

The Woburn Experimental Station has been under the charge of Dr. H. H. Mann during the whole of the period under report, Mr. T. W. Barnes has been chemist to the Station since 1929, and has remained during 1945–46. The farm foreman, Mr. W. A. McCallum, has continued in general charge of the farm while we have been assisted by various members of the Rothamsted staff as occasion arose.

From 1st October, 1946, the management of the Woburn farm has been turned over to Mr. J. R. Moffatt, the Farm Manager at Rothamsted; Dr. Mann will continue to be responsible for the control of the station as a whole.

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