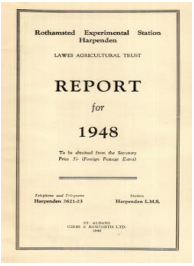
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ROTHAMSTED RESEARCH

Report for 1948

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PHYSICS DEPARTMENT

By R. K. Schofield

Dr. R. K. Schofield was appointed head of the Physics Department in succession to Dr. B. A. Keen. Dr. E. W. Russell resigned his position on the staff on becoming Reader in Soil Science at Oxford in October, 1948. Dr. C. Dakshinamurti concluded his voluntary work and obtained the Ph.D. degree of London University. Mr. M. L. Puri continued as a voluntary worker throughout the year. Mr. H. C. Aslyng, having been awarded a scholarship by the British Council, commenced as a voluntary worker in October, 1948.

Field Work

Deep ploughing

The germination and early growth of sugar beet was slowed up by deep ploughing in the long-term six-course experiment at Rothamsted, and the same effect was observed at most of the outside centres in 1948. By midsummer this backward growth was no longer noticeable at Rothamsted, the yield of clean beet was only reduced from 16·3 to 15·2 tons per acre, although the yield of tops was increased. At the outside centres this early check did not affect the yield of beet.

The advantage apparently obtained in 1947 by deep incorporation of fertilizers was not seen in 1948. Dr. Russell has arranged further experiments to be run from Oxford to test the effectiveness of ploughing down part or all of the potash and phosphate given to sugar beet and to lucerne.

Deep ploughing appears to have increased the average yield of potatoes in 1948 from 15 tons per acre to 18 tons per acre on the plots of the six-course experiment at Rothamsted where potash was put in the bouts. A similar effect in the same sense is shown in each year since the experiment was started in 1944, particularly in 1946 when the increase was 1½ tons per acre. It is too early to pronounce on the statistical significance of these results. None of the outside experiments on potatoes showed any benefit from deep ploughing in 1948.

Residual effects on the yield of winter wheat in 1946 from the deep ploughing and subsoiling for the preceding potato crop were obtained on ten out of thirteen fields. Deep ploughing appeared to give an improvement of about 1 cwt. per acre and subsoiling about 2 cwt. per acre. No residual effects in corn crops were found in nine experiments in 1947, but they were again observed in two out of five experiments in 1948. Over this period deep ploughing for corn itself has given an increase of 1–2 cwt. per acre in four out of ten experiments.

Intertillage, ridging and straw mulching for potatoes

This experiment was carried out for the third time in 1948. This year, owing to the very rapid early growth made by the potatoes, it was not possible to make any appreciable distinction between the intensively and the lightly cultivated plots. The results were in

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accord with those of previous years inasmuch as earthing up had no effect on total yield, or on the yield of saleable ware. On the other hand, the straw mulch increased the yield of ware from 11¾ to 13½ tons per acre, the increase being statistically significant.

Agricultural Meteorology

Measurements of evaporation

Observations of evaporation from open water, bare soil and turf have been maintained. It is satisfactory to be able to report that the evaporation per unit area of the standard Meteorological Office open water tank, which measures 6 ft. square, is the same as from our circular 2 ft. 6 in. diameter tank. The observations indicate that to get reliable readings the reflection of light from the sides and bottom of the tank must be minimized by suitable treatment of the surface.

Drainage from sandy soil

During 1947 and 1948 one of the cylinders filled with sandy soil has been used as a bare soil drain gauge 6 ft. deep and there has always been some daily drainage from it, even during the dry weather of 1947 when the ordinary drain gauges (local clay soil undisturbed) gave no discharge over a period of four months. This slow drainage from sandy soil has an important bearing on the assessment of water use of plants by soil sampling methods.

Control of irrigation by calculation of soil moisture deficit from meteorological data

The department has shared in an irrigation experiment on Mr. F. Secrett's farm at Milford, Surrey. The crop was sugar beet and there were three main watering treatments: unirrigated control (O), full irrigation at Mr. Secrett's discretion (F), and restricted irrigation based on weather data (R). A small weather station was fitted up on the field, and from records sent weekly to Rothamsted the transpiration was estimated and the trend of the estimated soil moisture followed throughout the growing season. Soil samples were taken at the beginning of the experiment and at the time of the maximum deficit: the estimated deficit by sampling agreed very well with the estimate based on weather. Wet periods immediately followed two of the three irrigations, so there were no major differences in results from the three treatments. The yields of sugar (cwt. per acre) were: O, 65·6: R (2·6 inches irrigation) 66·8: F (4·7 inches irrigation) 64·1.

The experiment is to be repeated in 1949.

Advice and service

Advice has been given to the Rother and Jury's Gut Catchment Board on an irrigation scheme for Walland Marsh, their engineer's estimate of summer water requirements being based on Rothamsted work.

Experience in the interpretation of data obtained from drain gauges has been placed at the service of the Land Drainage Legislation Sub-Committee of the Central Advisory Water Committee through its Technical Panel of which Dr. Schofield and Dr. Penman are members.

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Hygrometry and wind recording

The faulty switches in the recording electrical resistance thermometers used in the new type of dew point recorder have been scrapped, and switches designed and made in the departmental workshop have been fitted. The records now being obtained appear to be trustworthy and will be critically examined when enough have accumulated.

The hair hygrometers at 40 ft. and 80 ft. on the tower have been replaced by wet and dry bulb continuously recording electrical resistance thermometers. Alongside the thermometer screen are run-of-the-wind cup anemometers also giving a continuous record at ground level.

Instrument hut

A wooden hut has been set up in the pit in the meteorological enclosure. It is not so high that it will interfere with air flow over the site, but does offer an opportunity of protecting the less robust equipment necessary for our work in agricultural meteorology.

Soil shrinkage gauges

During the year we have set up a set of soil shrinkage gauges designed by the Building Research Station. In shrinkable clay soils such as ours, removal of water by plants causes shrinkage and at least one third of this shrinkage must be vertical so that an indicator in the root layer of the soil will move down (on drying) or up (on re-wetting) relative to a deep reference level well below the effects of root action. Plates have been set at 9, 6, 4, 3, 2, 1, 0·5 and 0 ft. from the surface. From their relative vertical movements information about transpiration losses will be obtained.

Micro-meteorology

The new instrument for the study of micro-meteorology among potato plants has worked satisfactorily, and a description of it is being published. Results show that wind movement inside the crop is slight, there are no marked temperature gradients within the crop, and when the soil is wet the temperature is greater in the crop than on the open headland. Under the same wet conditions there is a marked water vapour pressure gradient inside the crop, the vapour pressures at equivalent heights being greater inside the denser crop.

LABORATORY WORK

Measurement of the volumes of solids, water and air in soil clods

In connection with investigation of soil structure, soil moisture and soil aeration, means are required for measuring rather precisely the volumes of water and air contained in the total volume of a mass of soil in its field condition. A method developed by Russell, though considerably better than earlier methods, has not been entirely satisfactory. In a number of instances the sum of the volumes of water, air and solids has apparently exceeded the total volume. Further study has shown that the method originally adopted for obtaining the water content is inaccurate. This source of error has been practically eliminated by the use of the Dean and Stark apparatus in which the water is distilled off in boiling toluene. Several minor modifications have also been

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introduced, the total effect of which is both to speed up the determinations and increase their precision. It is hoped that in its revised form the method will be a useful research tool.

Vapour pressure of aqueous solutions

Existing data from which the vapour pressures of aqueous solutions of non-volatile solutes can be computed are not entirely concordant. As an aid to the selection of the most probable values, use has been made of the quantity Ψ defined by the equation

$$\Psi = \frac{p}{p_0 - p} - \frac{55{\cdot}51}{\nu m}$$

in which

55·51 is the number of moles of water in 1,000 grm. of water

m ,, ,, ,, ,, ,, ,, solute ,, ,, ,, ,, ,,

ν ,, ,, ,, ,, ions into which the solute molecule dissociates ($\nu = 1$ for non-electrolytes)

p ,, ,, vapour pressure of the solution

p_0 ,, ,, vapour pressure of water at the same temperature.

The most reliable data for solutions of sodium chloride and potassium chloride have been used to trace the variation of $\psi\sqrt{m}$ with $\sqrt{m}$ for each salt at 25°C. The graphs start from the value 10·83, when $m = 0$ (the limit obtained by applying the Debye-Hückel theory) and curve gently all the way to the saturation points. By tabulating the values of $\psi\sqrt{m}$ to two decimal places, full justice can be done to all existing data. For lower vapour pressure, data for sulphuric acid solutions have been similarly treated.

Directly determined vapour pressures of solutions of non-electrolytes appear to be less accurate, and the most probable values are obtained by using the isopiestic method to find the concentration of a solution of one of the above electrolytes which has the same vapour pressure. Several sets of data are available for sucrose and one for urea and glycerol. Measurements were made on dextrose and levulose as part of a study of the vapour pressure of honey. A solution obeying Raoult's Law would have a zero value of ψ. For sucrose, dextrose, levulose and glycerol ψ is the negative at all concentrations for which it can be determined with certainty, whereas for urea it is positive. Recent theories have been examined in an attempt to predict the trends of ψ at concentrations too low for accurate experimental determination. ψ is nearest to zero for glycerol, and the smoothness of change of its ψ with concentration provides a further sensitive check on the accuracy of the data for the electrolytes used as isopiestic standards.

This work is being prepared for publication.

Thickness of water films

There is considerable divergence of opinion regarding the causes of water retention in soil, and in particular on the factors that determine the thickness of water films covering the surfaces of the solid particles. Kussakov in Moscow has used an optical method to measure films as thin as one tenth of a wave-length of light. The soundness of Kussakov's method was demonstrated by preliminary work carried out at Dr. Schofield's suggestion in the Department of Technical Optics of Imperial College, London. An

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attempt is being made at Rothamsted to photograph the Newton's rings obtained with water films on mica. Gouy's theory of the ionic distribution in the diffuse component of the electric double layer has been extended by Dr. Schofield in order to calculate the maximum thicknesses that would be possible if the films were stabilized solely by the presence of exchangeable cations. Most of Kussakov's results confirm this idea but a few give film thickness in excess of the calculated values. It is primarily to check these results that this work has been undertaken.

Thermodynamic potentials of soil constituents

Theoretical studies suggest that the physico-chemical environment of the roots of plants growing in soil may be better expressed in terms of the thermodynamic potentials of bases such as potash, lime and magnesia and of acids such as phosphoric acid than by finding the quantities of these substances that can be extracted from the soil by various means. In order to test the usefulness of this concept, methods for measuring these potentials are being worked out. These investigations are still at a preliminary stage.

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CHEMISTRY DEPARTMENT

By E. M. CROWTHER

FERTILIZER PRACTICE

A number of papers were published on various aspects of fertilizer practice in the United Kingdom during the last ten years and in relation to the agricultural expansion programme.

FERTILIZER PLACEMENT FOR ROW CROPS

A special three-row drill for experimental work on fertilizer placement was built by the National Institute of Agricultural Engineering in 1946 and suitably modified after the first year's experience in the field. In 1948 it could be used to place fertilizer in any desired position near the seed in experiments of the normal pattern and with rapid adjustments of coulter settings and delivery rates.

In the very dry season of 1947 No. 2 National Compound Fertilizer (9% N, 7·5% P_2O_5, 4·5% K_2O) placed with or directly below sugar beet seed seriously damaged germination. Plant establishment was also reduced when the fertilizer was placed one inch to the side of the seed. For root crops side-band fertilizers containing nitrogen or potassium should therefore be kept more than one inch from the seed. There was, however, no advantage from any form of placement over broadcasting sugar beet fertilizers. For swedes placement in contact with the seed seriously depressed plant establishment but placement below the seed, either immediately below or to the side, gave higher yields than broadcasting. With peas a fertilizer containing 10% P_2O_5 and 20% K_2O injured germination when placed in contact with the seed but gave better yields when placed below the seed or in side-bands than when broadcast.

In five experiments in 1948 peas again showed considerable advantages from placing the fertilizer in side-bands below the seed. There was also a small gain from broadcasting on rough land several weeks before sowing over broadcasting immediately before sowing. In thirteen experiments on sugar beet and three on mangolds in 1948 there was no benefit in final yield from placing an NPK fertilizer in sidebands over broadcasting, though the placed fertilizer sometimes gave more vigorous early growth. Bands one inch to the side of the seed caused slow and irregular germination at most centres.

SUGAR BEET MANURING

Two series of sugar beet manurial experiments were continued in 1948 in collaboration with the British Sugar Corporation. One series, at about twenty centres, annually tested N,P,K,Na and B fertilizers. Another, at a smaller number of centres, compared ammonium sulphate and sodium nitrate at two rates and in the presence and absence of sodium chloride; all plots received 0·6 cwt. P_2O_5 per acre as superphosphate and 0·3 cwt. K_2O per acre as chloride. The sodium chloride at 3·5 cwt. per acre contained as much sodium as the double dressing of sodium nitrate. The average results of 17 experiments in 1945 to 1947 are summarized

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below (one experiment on an irregular site was omitted because very acid raw subsoil was brought up by deep ploughing shortly before sowing the beet).

Mean yields of Sugar in cwt. per acre

	No sodium chloride	With sodium chloride	Difference
No nitrogen ...	36·4	39·1	2·7
Ammonium sulphate			
0·4 cwt. N per acre	42·1	45·2	3·1
0·8 cwt. N per acre	43·4	47·5	4·1
Sodium nitrate			
0·4 cwt. N per acre	45·9	46·9	1·0
0·8 cwt. N per acre	48·9	48·3	–0·6

Sodium nitrate was much better than ammonium sulphate where no sodium chloride was given; ammonium sulphate and sodium chloride gave results approaching those from sodium nitrate alone. Sodium nitrate should be regarded as supplying two plant nutrients for sugar beet. Where it is used at fairly heavy rates there is no need to provide additional sodium chloride.

As would be expected the superiority of sodium nitrate over ammonium sulphate showed more markedly on the lighter soils which are commonly deficient in sodium and potassium.

Manuring of Peas

In collaboration with the staff of the Home Grown Threshed Peas Joint Committee and the National Agricultural Advisory Services field experiments have been carried out on a uniform plan each season since 1946. Ammonium sulphate, superphosphate and potassium chloride, each at three rates (0, 1, 2), were tested in all 27 combinations. The average results of 18 experiments in three seasons 1946 to 1948 are given below for the principal treatments.

Mean yield of threshed Peas in cwt. per acre

Fertilizer dressings in cwt. plant-food per acre

No N	16·2	No P_2O_5	16·0	No K_2O	15·6
0·2 N	16·1	0·5 P_2O_5	16·2	0·6 K_2O	16·3
0·4 N	16·3	1·0 P_2O_5	16·4	1·2 K_2O	16·6

Nitrogen had no effect. There was a large response to phosphate in one experiment but significant depressions in three others; the average benefit was very small. The double dressing of potassium fertilizer increased the yield in 14 out of 17 trials and the average gain was highly profitable. In the six centres classed as "very low" in readily soluble potassium by a rapid method of soil analysis the average response to the higher dressing was 2·4 cwt. threshed peas per acre, as compared with only 0·3 cwt. per acre in the eleven centres with more readily soluble potassium. The main manurial requirement of peas is potassium fertilizer, especially on soils deficient in available potassium. Phosphate fertilizers are needed only in a few acutely deficient soils, but a potassic superphosphate high in potash could supply potassium in a drillable form and also

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cover any risk of phosphate deficiency. Suitable mixtures are not at present offered by manufacturers; their introduction, especially in a granular form, is urgently needed for peas and for winter cereals to be combine-drilled on soils deficient in readily soluble potassium.

Bulky Organic Manures

The Agricultural Research Council Conference on Sewage Sludge and Composts has published a memorandum (Ministry of Agriculture Technical Communication No. 7) which summarizes the results of a series of over a hundred field experiments carried out by the Chemistry Department in different parts of England in recent years. The report also includes average analyses of a large number of samples of different kinds of sewage sludge.

Sewage sludge has a moderate manurial value as a source of slowly available nitrogen and phosphate with very little potash. In general the crop-producing power of sludges taken from drying beds is much less than that of equal weight of farmyard manure. The physical effects of sewage sludge on the soil are less pronounced and of a different kind from those of farmyard manure because sewage sludge lacks the coarse fibrous ingredients derived from straw and other plant residues.

Digestion improves the physical condition of sludge and the availability of its nitrogen. Certain sludges from sewages of industrial origin contain iron and other heavy metals which may render the phosphate unavailable and may even be toxic to crops.

Composts prepared with one-and-a-half parts of sludge dry matter to one part of straw proved better than sewage sludge alone but were somewhat inferior to equal quantities of farmyard manure.

Field trials at Rothamsted and elsewhere have shown that composts from straw and inorganic nitrogen have only low manurial value. Recent laboratory investigations have shown that the total amount of nitrogen immobilized by straw is much the same whether the straw and inorganic nitrogen are added directly to the soil or previously subjected to composting. Where inorganic nitrogen is added at the rate of one part per hundred of straw little, if any, of the nitrogen immobilized is subsequently liberated in the soil as ammonia or nitrate, at least in experiments with composting for two months at 30°C. and subsequent decomposition in soil for three months at 23°C. (About one-half of the organic matter of the straw was lost in the composting process.) These laboratory experiments suggest that previous rotting of straw has little effect on the amount of nitrogen which ultimately becomes available in the soil from a given amount of straw and nitrogen fertilizer. They also emphasize the low availability to plants of the nitrogen locked up during the rotting of straw. Earlier field and pot experiments had shown that amounts of inorganic nitrogen, readily nitrifiable nitrogen or the nitrogen per cent. of organic matter often gave reasonable guides to the immediate availability of the nitrogen in a wide variety of rotted manures and composts.

Analysis on a number of experimental composts prepared under practical conditions revealed a possible source of error in attempts to draw up nutrient balance sheets. Repeated turning of the heaps had led to considerable admixture of nutrient-rich soil from the floor of the compost-shed.

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A number of experiments were carried out in forest nurseries to test how far the manurial effects of composts depended on factors other than their contents of readily available nutrients.

Nutrition Problems in Forest Nurseries

Work in collaboration with the Research Branch of the Forestry Commission was continued on conifer seedlings in several nurseries in 1948.

A sharp distinction must be drawn between problems encountered in nurseries on very acid soils cleared from heath or forest and those on less acid or neutral soils in many of the "established" nurseries on what was previously agricultural land. On the very acid soils good first-year seedlings and second-year transplants can be grown provided nitrogen, phosphorus and potassium are supplied either in fertilizers or composts. Good results have been obtained with inorganic fertilizers alone, though the best times and methods of applying inorganic nitrogen to transplants have still to be found. In one experiment on very acid light soil at Wareham, Dorset, transplants top-dressed with ammonium sulphate were scorched during spells of hot weather; those with other soluble nitrogen fertilizers grew well.

On neutral or moderately acid soils in "established" nurseries Sitka spruce seedlings often grow very poorly indeed, even with composts or fertilizers. Although the precise cause of the failure has not yet been determined, marked improvements have been obtained by using steam, formalin and several methods of acidifying the soil. Ammonium sulphate at the rate of one ton per acre, applied during the winter, proved to be a convenient and effective method of acidifying the soils.

At three nurseries pH range experiments were laid out in 1948, the adjustments of soil reactions being made by graded dressings of aluminium sulphate and calcium carbonate. In preliminary first-year tests several species of tree seedlings showed pronounced pH optima. When the disturbing effects of surplus salts wear off, it may become possible to determine the pH optima more precisely and to study a number of nutritional factors related to soil reaction.

First-year seedlings and second-year transplants raised with fertilizers or composts grew well in planting experiments in several forests. The first-year seedlings gave relatively large increases in height and diameter from fertilizers applied near the time of planting. It is proposed to follow the effect of manurial treatments in the nursery and the forest on the subsequent growth of the trees over many years.

Some of the characteristic features of conifer seedlings in various nurseries were shown in Sitka spruce grown on soil samples in small scale pot experiments at Rothamsted.

Soil Organic Matter

Investigations on the extraction and fractionation of soil organic matter have often been limited by the difficulties of determining organic carbon in soil extracts. It has recently been found that the Van Slyke-Neil manometric apparatus can be used for determining both organic and inorganic carbon in soils and organic carbon in soil extracts. The organic carbon is determined by the

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method of Van Slyke and Fulch and inorganic carbon by a modification of the same method. Both methods are as accurate as established procedures and can deal with micro-quantities of material. They are rapid and simple and seem well suited for the routine analysis of soils and soil extracts.

By using these new methods it was possible to extend earlier work on the extraction of soil organic matter by alkali, sodium pyrophosphate or other salts forming insoluble calcium compounds or soluble complexes with heavy metals. The ratio of carbon to nitrogen in the extract was constant for any given extractant but sodium hydroxide gave lower carbon-nitrogen ratios in the extracts than the salts. The difference was particularly great with fen soils for which the carbon-nitrogen ratio with sodium hydroxide was about half of that with the salts.

The fact that alkaline extracts of soils are appreciably oxidized in air is objectionable for some purposes. It has, however, been found that the amount of organic matter extracted from soil by alkali does not depend on such oxidation, the same quantities being extracted in nitrogen and in air.

Earlier work on the extraction of soil organic matter and on the nature of the organic nitrogen of soils has been continued and papers prepared for publication.

Soil Manganese

Earlier work in collaboration with the Biochemistry Department on the various forms of manganese in soils was written up for publication. In continuing the investigation it was found that the proportion of the total manganese extracted by ammonium acetate containing 0·2 per cent. hydroquinone decreased rapidly with increasing soil carbon over a range of soils. Although hydroquinone and sodium hydrosulphite in ammonium acetate extract similar amounts of manganese from mineral soils, they behave quite differently with organic soils. The uptake by organic soils of manganese added in ammonium acetate is not much affected by the presence of hydroquinone but is greatly diminished by the presence of hydrosulphite. Ammonium acetate containing hydrosulphite extracts relatively large amounts of manganese and iron from organic soils. Low values for readily reducible manganese as determined by hydroquinone do not necessarily imply that the soils have low contents of higher oxides of manganese. Manganese ions formed by the hydroquinone may be taken up again by the soil organic matter.

The reducing powers of neutral pyrophosphate extracts of organic soils were estimated from the amounts of manganese dissolved after adding manganese dioxide. The values obtained were little altered by storing or aerating the extracts in more alkaline conditions, but were very sensitive to the amounts of pyrophosphate used to dilute the extracts before adding the manganese dioxide. They were also altered by adding manganese or copper salts. The equilibria in systems containing manganese in complexes with either inorganic or organic materials need elucidation before suitable extractants can be employed to determine the forms of the more active manganese in organic soils.

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Fluorine in Soils

The analytical determination of small amounts of fluorine in soil has been improved, and an account prepared for publication. The method has been used to follow the fate of fluorine added in superphosphate in long-continued manurial experiments at Rothamsted and Saxmundham. It appears that a considerable proportion of this fluorine is lost from the soil by leaching. The fluorine contents of the soils studied, including those without fertilizers containing fluorine, are frequently greater than the amounts added in superphosphate in annual dressings over long periods. The native soil fluorine is, in fact, more than would be required to convert all the soil phosphate to fluorapatite, though there is some evidence that neither the fluorine nor the phosphorus is present in the soil mainly as fluorapatite.

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PEDOLOGY DEPARTMENT

The general programme of work outlined in the 1947 report has been continued. Professor Mannkopff and Mr. Albrecht completed their work in the spectrographic section and during the summer Professor Mannkopff held a very successful course in spectrography which was attended by several workers from other laboratories.

It is with deep regret that we record the death of Dr. J. B. Hale, who was in charge of the spectrographic section.

Dr. E. M. Chenery, formerly at Trinidad, is continuing and extending his study of aluminium accumulator plants.

Weathering of Rocks and Minerals

The examination of the Malvern rocks and soils described in last year's report is continuing. The Malvern Hills region is particularly well suited to the study of the magnesium-iron mica biotite, as rock types very rich in biotite occur in the crystalline complex. The weathering of this mineral can best be studied by taking a compact block of the rock, and dissecting it so as to show the transition from the fresh core specimen to the outer weathering crust. X-ray diagrams of the biotite flakes in the fresh, the slightly weathered and the highly weathered condition have been obtained. Thin sections provide supplementary evidence of the stages of decomposition. As revealed by these two methods the main trend of weathering is primarily towards a chloritic product. A characteristic feature of a residual soil profile derived from highly weathered biotitic rock is the presence in the sand fraction of yellowish-brown micaceous minerals with a golden or bronzy lustre. All stages in the transition from the chloritic weathering product of biotite to this mineral are traceable. Its identity with vermiculite is suggested by both X-ray and optical determinations, as well as by its ready exfoliation by H_2O_2 in the cold.

Particular attention is being given to characterizing by X-ray analysis the clay fractions (<2 microns) separated from the soils. A point of interest is that a trioctahedral mica occurs both as a weathering product and as a component of the clay fractions of soils derived from the more basic members of the rock complex. This is paralleled by G. F. Walker's work in Aberdeenshire (*Clay Min. Bull.*, 1947, No. 1, 5–7).

Clay Mineral Studies

Adsorption complexes of α-zinc hydroxide. A series of complexes of α-zinc hydroxide with anionic dyestuffs (especially Naphthol Yellow) has been discovered, having partially ordered layer lattices with characteristic basal spacings. The degree of order in the random packing of layers in the complexes is a direct function of the concentration of the dyestuff present during the precipitation of the α-zinc hydroxide. There is a critical dye concentration at which the layer lattice changes from the non-expanding to the expanding type.

The primary complex of the "expanding" type forms secondary complexes with water, the hydroxy compounds (primary alcohols, glycols, glycerol and aqueous solutions of the saccharides) and the nitriles of the aliphatic series showing a corresponding increase in

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the basal spacing. This behaviour is similar to that of kaolinite and montmorillonite but only qualitatively. In addition, no complexes could be obtained with organic liquids of high dipole moment (e.g. nitromethane, nitrobenzene) which are so strongly taken up by the clay minerals.

Location of adsorbed ions and molecules of montmorillonite. The investigation of the montmorillonite/nitrile complexes has been completed. The results show that the amount of water present in the clay has an appreciable effect on complex formation by these liquids.

A detailed Fourier investigation of the (000) reflections of montmorillonite and hectorite, saturated with various exchangeable cations, has been undertaken to elucidate the structure of these minerals and especially to find the positions occupied by these ions in the lattice. A Kipp recording microphotometer has been set up and adjusted for use in this work.

In addition to these special investigations a number of clays from soils and clay deposits have been examined. A sample of brick-making clay from the Keuper Marl, near Birmingham (supplied by the Building Research Station) has been examined in detail. It contains what is believed to be a new type of clay mineral, a hydrated chlorite. Further work is being done on related materials.

A series of English soil clays (nine complete profiles) of interest in connection with the Summer Excursion of the Commonwealth Conference on Tropical Agriculture has been examined.

Spectrographic Work

The glass spectrograph designed by Professor Mannkopff was completed and is now in operation. The other instruments have also been set up and some preliminary work is being carried out with both the glass and large quartz spectrographs, but not as much has been done so far as had been hoped, owing to the sad loss of Dr. Hale. The dispersion curves of both instruments have now been obtained and standard photographs have been made indicating the positions of the principal lines of most of the elements. Some work has also been done on the relative characteristics of different types of photographic plates.

The medium quartz spectrograph is now in routine operation using the Lundegardh flame method.

Gleying in Soils

The study of the gleying process has been continued mainly as a laboratory problem. It is hoped that by the summer this side of the investigation will be sufficiently far advanced to permit a profitable extension to cover field conditions.

A soil may be gleyed artificially in the laboratory by anaerobic incubation in a sugar medium, the process being usually completed in about two weeks. The fermentation produces a marked change in the appearance of the clay, and starting with clays of different colours the final colour is a light slate-blue. The colour change begins at isolated places throughout the body of the clay, and gradually extends until finally the whole mass is a uniform blue colour. In addition to the colour change, considerable solution of iron occurs, the clay is flocculated and is impregnated with a gummy material which may be responsible for the blue colour

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since treatment with hydrogen peroxide quickly destroys the organic material and leaves an almost white clay. At the end of such a fermentation the supernatant solution contains much ferrous iron in the form of the lactate, propionate, etc. The solution oxidizes rapidly on exposure to air, and unless the pH has fallen to a very low value this is accompanied by hydrolysis and the precipitation of bulky yellowish-red basic ferric compounds.

It has been found by experiment that it is possible to remove iron from clay by incubation under less anaerobic conditions. In such cases the solution is dark red-brown in colour, contains no ferrous iron, and does not give a precipitate on prolonged exposure to air. This degree of stability may be due either to complex formation, or to the development of too low a pH to permit hydrolysis.

(If reducible sulphur compounds are present, hydrogen sulphide is almost invariably formed and the clay is blackened by a precipitate of ferrous sulphide.)

The bleaching of the surfaces of structural elements in heavy textured subsoils is also a reduction effect. The associated rusty mottling is due to the hydrolysis of the iron-organic complexes and precipitation of a hydrous oxide. In addition soluble iron compounds which diffuse to the surface of the bleached layer would tend to be removed from the system by fresh water percolating down the profile. Thus it seems that the overall tendency of the process is the complete removal of the iron, and this suggests a strong affinity with the process of podzolization.

From a consideration of the products of bacterial fermentation of sugars it is obvious that the formation of complexes with ferric, and possibly ferrous, iron is highly probable. It is well known that many ferric organic complexes suffer reduction on exposure to light (cf. Schofield's work on the oxalate treatment of clays). Ignatieff has reported an increase in the ferrous iron content of gleyed soils on exposure to light, which tends to confirm that such ferric complexes are found in natural gleys. In addition, the energy required to reduce ferric iron to the ferrous form, in the ionic state, is considerable so that it does not seem feasible that the process can occur as such under natural conditions. It therefore seems possible that the process actually occurs via complex formation with organic compounds. This aspect of the problem is being studied. Preliminary work suggests that the formation of ferrous complexes is not likely to occur extensively. The hydrolysis of inorganic ferric salts is so pronounced that considerable difficulty is experienced in investigating the ferric complexes conductimetrically, since attempts to increase the pH of the solution, to values at which complex formation is possible, by the addition of a base result in such a large increase in the conductance that the relatively small changes in conductance being sought are completely masked. A potentiometric method is therefore being used.

Investigations on the Bio-geochemistry of Aluminium

A survey of the occurrence of aluminium in the plant world has been completed. In this over 2,000 strongly accumulating species were brought to light. The significance of these plants in tropical ecology is being studied.

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SOIL MICROBIOLOGY

By H. G. THORNTON

The following main lines of work were carried out during the year.

MICROPOPULATION OF BROADBALK PLOTS

The development in this department of improved methods of estimating numbers of micro-organisms in soil has made it desirable to examine by their aid the effects of the prolonged differences in manuring of our classical plots on the main groups of the micro-population. The present survey has the particular object of comparing the effects of artificials and farmyard manure. In 1946–47 a series of samples, taken from three plots in Barnfield, showed that Plot 4a, treated with complete minerals and ammonium sulphate had somewhat higher numbers of bacteria than the unmanured plot 8–0, but less than the dung plot 1–0. The numbers of active amoebae in this plot were as high as in the dung plot and much higher than in the unmanured. Since the treatments in the classical plots are not replicated, it was decided to check these apparent effects of manuring by surveying the micropopulation of plots, similarly manured, in quite a different field.

During the season, therefore, a team of workers has examined samples of plants and soil taken at intervals from three plots from Broadbalk, namely Plot 2 (farmyard manure), Plot 3 (unmanured) and Plot 7 (complete minerals and ammonium sulphate).

Dr. Janet Mollison has made microscope measurements of the total lengths of mycelium and compared these with colony counts of fungi. Mr. P. C. T. Jones has made microscope counts of the number of bacterial cells. Mr. F. A. Skinner has made plate counts of bacteria and actinomycetes both in the soil and in root-washings from the crop, while Dr. B. N. Singh has made dilution counts of amoebae. The full results of this survey are not yet to hand, but already they tend to confirm the results of the previous survey of Barnfield plots and also to show some correspondence between the results of the different methods used.

COMPARISON OF PLATE AND MICROSCOPE COUNTS OF BACTERIA

A serious discrepancy exists between the large numbers obtained when total numbers of bacterial cells are counted in stained films of soil and the much smaller estimates derived from counts of colonies on dilution platings. This discrepancy could be due to several causes such as the counting of non-viable cells in stained films, the inadequate dispersion of the bacteria in the suspension plated, or failure of the plating medium to support growth of many species of the soil bacteria. The last explanation, if true, would involve the conclusion that most species of soil bacteria have so far escaped cultivation and laboratory study. Hence an explanation of the discrepancy is fundamental to soil bacteriology. Mr. P. C. T. Jones is investigating this problem by applying both methods to cultures added to sterilized soil. The data obtained from the survey of Broadbalk plots should provide evidence of any effect that season or manuring may have on the ratio of direct to plate counts.

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It is also important to narrow the ratio by developing a plating medium that will give the highest colony counts consistent with accuracy. Mr. F. A. Skinner has studied this problem and has developed a medium giving much increased colony counts with good agreement between replicate plates.

Nitrification

A question never clearly settled with regard to the nitrification of ammonia in soil is the contrast between the ease with which this occurs in highly organic soils and the claim that quite small amounts of soluble organic compounds kill or inhibit the activity of nitrifying bacteria in culture. Dr. Jane Meiklejohn has investigated this problem by adding glucose to cultures of nitrifying bacteria growing in mixture with other organisms. The glucose temporarily inhibited nitrification without killing the nitrifying bacteria by encouraging growth and resulting competition by the other bacteria present. Nitrification was resumed as soon as the added glucose had been consumed. An isolation of Nitrosomonas has been obtained and is being studied.

Myxobacteria

Following his studies of this interesting group, Dr. B. N. Singh has searched soil samples from Canada, Jan Mayen, Sweden, Holland and Australia, for Myxobacteria of the types that produce fruiting bodies and consume Eubacteria. He has found these diverse soils to contain species identical or similar to those in British soils. Isolations of simpler types of Myxobacteria that appear not to produce fruiting bodies have also been made and are being studied.

Soil Amoebae

During the surveys of Barnfield and Broadbalk plots a number of new strains of amoebae have been obtained and studied in laboratory culture. Some of these have been used by Miss Lettice Crump to study the environmental factors that induce hatching of the cysts. She has obtained evidence, *first*, that the type of bacterial food consumed by the amoebae before encystment may affect the subsequent viability of the cysts, and, *secondly*, that, with one of the amoebae studied, excystment takes place only in the presence of bacteria, the species of which is again of importance.

Miss Crump has also studied the rate of spread of amoebae in sterilized soil inoculated with bacteria and finds that this rate varies with the species of amoebae and with the type of bacterial food. These studies on the inter-relation of amoebae and bacteria have an obvious bearing on our understanding of the ecology of the soil's micropopulation.

Antibiotic Activities of the Soil Microflora

Previous workers studying the antagonistic action between colonies of soil micro-organisms growing on plates, have usually employed media rich in nutrients and having a high concentration of mineral salts. Such an environment is very different from that found in normal soil in which the content of available nutrients and of soluble salts is very much lower. The present investigation by Mr. F. A. Skinner began with an attempt to obtain a plating

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medium that would give high colony counts of bacteria and actinomycetes from a plated soil suspension, by discouraging suppression of growth through competition between colonies. It was found that reduction of the available nutrients and a much higher dilution of the salts in the medium greatly increased the colony count; the highest counts were indeed obtained with no added organic compounds other than washed agar, although on this medium the colonies formed were too minute for routine counting.

The suppression of bacterial colonies in the neighbourhood of actinomycetes has so far been observed only on the richer media containing beef extract and peptone, but the suppression of fungal growth by actinomycetes has been noted usually on the medium with dilute salts and from 100 to 10,000 p.p.m. of glucose or of mannitol. Antagonism between two species of actinomycetes has so far been found only on media with not more than 100 p.p.m. of soluble carbohydrate. On such media the actinomycetes grow rapidly and show the well developed aerial mycelium and lack of pigmentation that has been found to characterize their growth on moist soil. The antibiotic activity of isolates are now being studied under a variety of environmental conditions.

The Relation of Micro-organisms to Soil Structure

Dr. R. J. Swaby has finished his study of the action of micro-organisms on soil aggregation described in last year's report. He concluded that the quantity of fungal mycelium found in a sample of field soil might account for about a quarter to a half of the observed aggregation while bacterial colonies seemed of little quantitative importance in this respect. A large fraction of the aggregation was thus not accounted for by such immediate effects of micro-organisms, but was perhaps attributable to some resistant humus complex.

Mycorrhizal Infection of Crop Plants

Dr. Janet Mollison has made an examination of the roots of wheat taken at intervals from Broadbalk Plots 2, 3, 5 and 7 and also from Great Harpenden field, where, in contrast to Broadbalk, wheat had not been previously grown for six years. Early in the season, wheat seedling roots from the unmanured Plot 3 showed a greater degree of mycorrhizal infection by the phycomycete fungus, than those from any of the treated plots, though this difference decreased with the age of the plants. No difference in the incidence of the infection was found between the variously treated plots, whether given artificials or farmyard manure. In contrast, however, the wheat collected from Great Harpenden field showed little mycorrhizal infection until late in the season and even then it was less widespread than on the Broadbalk plots.

Pot experiments designed to study the spread of mycorrhizal infection in clover have shown that the fungus failed to establish itself in sterilized soil, either from chopped infected roots or from infected seedlings planted in it. Such seedlings did not even show infection of new roots, the infections remaining localized. Investigation of the factors that effect the spread of the fungus outside the plant are continuing.

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Geographical Distribution of the Bacteria

A study of the distribution over Great Britain of strains of clover nodule bacteria, effective and ineffective in fixing nitrogen has been continued this season, strains isolated in 1947 having been tested on the plant and more strains obtained from new areas in the North and West of England. We have received most useful help from members of the National Agricultural Advisory Service in this work.

Establishment of Clover Nodule Bacteria when inoculated into Field Soil

This problem is of great importance to the practice of legume seed inoculation and is being studied in field trials at a number of centres. At each centre replicated plots are sown with clover inoculated with each of three strains of nodule bacteria and with uninoculated seed. Bacteria are isolated from 100 nodules per treatment as well as from the uninoculated plots and these isolations are tested serologically to determine how many are derived from the culture used to inoculate the treated plots, and how many from the "wild" nodule bacteria in the soil. This work involves the isolation and testing of bacteria from 400 nodules per experiment, of which some dozen have been run. Miss Margaret Thomas has charge of this research and carries out the laboratory work at Rothamsted. Great assistance, moreover, has been given us by members of the National Agricultural Advisory Service, not only in carrying out the field trials but also in making many hundred isolations of bacteria from nodules. Without this help the extensive programme could not have been carried out. Individual acknowledgment will be made at the conclusion of the investigation.

The serological testing of strains isolated from field experiments carried out in 1947 has been completed, and one strain used for seed inoculation has competed successfully with local strains in four out of six experiments, producing over 60 per cent. of the nodules in some cases. The other two strains employed have given poor establishment, and, although highly effective in laboratory culture, would not prove of any value in large-scale field inoculation.

Similar field experiments have been carried out in 1948 but in the areas of hill pastures at 500 to 1,000 feet in Wales, Scotland and Yorkshire. Further effective strains of Rhizobium have been used to replace those which proved unsatisfactory last year. Isolations have been made from all experiments, including three continued from 1947, and serological testing of the cultures is in progress.

Local Adaptation of Clover Bacteria

An extensive experiment was made by Dr. P. S. Nutman and Miss Margaret Thomas, with help from the Statistical Department, to determine whether adaptation occurs between local strains of red clover and the indigenous strains of nodule bacteria in districts where the clover strains are grown.

The experiment comprised three English and six Swedish strains of clover, and 50 local strains of bacteria, each of which was tested effectivity on each strain of plant. Significant evidence was found of local adaptation in Sweden.

Dissociation of Nodule Bacteria in Soil

Dr. Janina Kleczkowska continued her work on the appearance of ineffective dissociant forms of clover nodule bacteria, when

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effective strains are kept in sterilised soil. Ten effective strains were stored for 2 years in Woburn soil, plated and bacteria from random colonies were tested on clover plants. Two of the strains were found to have produced ineffective dissociant forms but the remaining eight remained stable. Genetical stability in soil thus appears to be a strain character, a conclusion of importance in selecting strains for use in the practice of legume inoculation.

A second experiment in which clover bacteria are being stored in 15 different types of soil, is still in progress.

Dissociation under the Action of Bacteriophage

When nodule bacteria are exposed to bacteriophage, dissociant forms are readily produced, particularly frequent being changes in colony appearance, such as change to "roughness" or pigment formation. Less frequent are changes influencing the effectivity effects in nitrogen fixation within the nodule. Dr. Kleczkowska, however, has obtained strains effective and intermediate in this respect by treating ineffective parent strains with bacteriophage and conversely has readily obtained ineffective dissociates from 'phage-treated effective strains. The action of 'phage has also induced changes in the morphology of the bacterial cells, which are being studied.

Genetical Factors in Clover affecting Nodule Development

This work by Dr. P. S. Nutman, described in previous reports, has now reached its final stages with the examination of material from crosses made in order to complete evidence on some doubtful points. The work is being prepared for publication at an early date.

Physiology of Infection

Further experiments with delayed inoculation of clover with nodule bacteria have confirmed the results given in the two papers submitted to the Annals of Botany. The suggestion that the apical meristems of lateral roots and of effective nodules inhibit nodule formation in their neighbourhood has received strong support from the discovery that excision of these root apices and nodules increases the number of nodules formed, while the excision of ineffective nodules (which have no persistent apical meristem) has no such effect.

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BOTANY DEPARTMENT

By WINIFRED E. BRENCHLEY

MINOR ELEMENTS—MOLYBDENUM

Action in nutrient solutions

Work on the response of the plant to molybdenum under varied nutrient conditions has been continued, attention being chiefly focused on alterations in (1) pH value and (2) nitrogen supply.

(1) The uptake of molybdenum is known to be greater from alkaline than from acid soils, as it is rendered more available under the former conditions. Theoretically, there should be no molybdenum present in nutrient solutions to become available, but nevertheless some difference in response to the element might be expected with a change in the reaction of the medium. Investigations were carried out to determine if this were the case, using two nutrient solutions of quite different chemical composition and with normal pH values of 5·6 and 6·4 respectively. With these as bases, two series of solutions were prepared, by appropriate addition of acid and alkali so that a pH range of approximately 4·0 to 8·0 was covered. Lettuce and red clover plants were grown in the resulting modified solutions, with and without the addition of 0·2 p.p.m. of Mo., as sodium molybdate. It is common knowledge that once contact with the plant roots has been made, rapid changes in pH values occur, and solutions which at the outset differ widely in reaction, quickly level up and ultimately closely resemble each other. Records made during the present investigation completely confirmed this. The type and amount of growth in each solution, however, was by no means similar, though it was realised that the differences were probably due chiefly to indirect effects, such as availability of iron, rather than to changes in the pH value itself. The results with lettuce and red clover were very similar. Some solutions were more favourable to growth than others, the most acid causing a check to root development in the early stages but ultimately producing some of the best plants. The most alkaline solution was the least satisfactory, the shoot showing the damage in this case. Molybdenum deficiency symptoms were recorded in all types of solution, though they were less marked and sometimes absent altogether in the most alkaline medium. It is not yet clear whether this latter effect was directly attributable to the nature of the solution, or whether, with the concomitant reduction in size and vigour of the plant, its demand for molybdenum was so small, that the original trace probably present in the seed sufficed.

(2) A close association exists between molybdenum and nitrogen nutrition. Investigations have been begun to determine the response of the plant to molydenum in nutrient solutions supplying different levels of nitrogen. The behaviour of a leguminous crop, red clover, with and without inoculation is being compared with a non-leguminous crop, lettuce.

Toxicity of molybdenum in different soils

Studies of the effect of toxic dressings of molybdenum on flax and red clover were continued, with special reference to manganese deficient soils. Flax was grown in small glazed pots as before, but

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the red clover was sown in deeper ones following the experience of 1947 when the plants became pot-bound by the end of their first season.

Three soils were used. The fertile sandy Woburn and the manganese-deficient fen soil were the same as in 1947, and a clay soil from Tring was introduced as an example of a soil different from the fen, but showing similar deficiency of manganese on analysis. Both the manganese-deficient soils were used with and without added manganese.

Growth of both crops in fen soil with and without added manganese was similar to that of the previous year, acute symptoms of manganese deficiency appearing unless manganese had been added. The plants in fen soil with manganese were not as good as those in Woburn soil, which were very tall and sturdy and much quicker in developing.

Plants in Tring soil behaved quite differently from those in fen, showing hardly any symptoms of manganese deficiency and consequently little benefit from added manganese. Flax in Tring soil was slow in starting and by harvest was considerably smaller than in Woburn soil; in the presence of manganese it was slightly smaller than in fen soil. Red clover in Tring soil made reasonably good growth after a slow start.

Molybdenum was given at three rates as soon as the plants were established, and half of these treated plants received a second dressing at half the original rate later in the season.

Molybdenum toxicity was more severe in Woburn soil than in 1947, the highest dressings killing many plants of both crops and the lower dressings producing typical brownish-orange discoloration of stems and leaves and reduction of size of plant. Plants in the other two soils were less severely affected by the molybdenum. In the fen soil without manganese the plants were so poor that molybdenum toxicity was almost masked, and where manganese was added the symptoms were much less acute than in Woburn soil. Tring soil either with or without manganese showed very little effect of molybdenum. Symptoms were very late in appearing and were confined to slight yellowing and slight reduction in size of plants.

No interaction of molybdenum with manganese deficiency was noted in flax, but in clover a month after the second cut plants grown in fen soil without manganese but receiving molybdenum began to show a slight improvement in colour over the corresponding no molybdenum set. This is similar to the effect observed in the winter of 1947. No such effect has shown in Tring soil, but as the plants did not show symptoms of manganese deficiency it was hardly to be expected. The final results will not be available for some time.

Effect of molybdenum on tomatoes with different basal dressings of manure

Tomatoes grown in a molybdenum experiment in 1947 produced many fruits with hard core and blossom-end rot, so an experiment was set up to see if this could be avoided by any modification of the fertilizer used.

Tomato plants were grown in large earthenware pots of Woburn soil with two different basal dressings. One consisted of hoof meal and dry fertilizers given when the plants were finally potted up, and

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the other of nutrients given in solution at 10-day intervals. Both were used in conjunction with three levels of potash.

The most striking result was the healthy colour of plants, high yield and freedom from blossom-end rot in fruits of the set having hoof and dry fertilizers contrasted with the others. Unfortunately this otherwise good set produced a far bigger proportion of fruits with hard-core than did the set receiving a nutrient solution at regular intervals. Effects of level of potash were much less noticeable than those due to type of fertilizer.

Effect of root temperature on growth of plants in water culture

The investigations outlined in the 1947 report were extended using the same apparatus and solutions. Continuous shading was discontinued and further attention was given to the effects of controlling root temperature under the normal glass-house practice of shading only on very sunny days.

Three controlled root temperatures were used—high and low as before, plus an intermediate one—and plants were also grown on the bench with fluctuating temperature. Peas and flax were grown again as the varieties used had proved satisfactory, but buckwheat was discontinued as no pure line or named variety was available and the replicates were very uneven. A preliminary experiment with radishes suggested that they were considerably affected by root temperature and would be good subjects for further studies.

Weed Investigations

The estimation of the vitality of buried weed seeds in the soil samples taken from Broadbalk wheat field in 1945 have been completed. Data are now available to compare the results with the 1940 sampling from the same plots and thus to determine the effects of another 5-year fallowing cycle on the weed flora.

Observational records on the weeds present on Broadbalk and Hoos fields during the cropping period have been made as usual.

The long term pot experiments on dormancy of wild oat seeds continued, but very few seedlings appeared. This suggests that most of the viable seeds had germinated during the previous three years. Another third of the deep-sown wild oat pots were tipped out into seed boxes in the autumn, but at the time of writing no seedlings have appeared.

Suggestions for the control of wild oats continue to come in from farmers and others, and are being noted with a view to setting up a field experiment on this problem in the near future.

Park Grass and Highfield

The botanical analyses of hay from certain selected plots on Park Grass have been continued. A start has been made in working up the data accumulated since 1919 with a view to incorporating it in a new edition of the monograph "Manuring of Grassland for Hay". All the information available to date will be thus brought into line together.

In view of the changes about to be made in the nature of the investigation on Highfield, which will involve ploughing up of the grassland, only the three plots needed to complete the data from the original experiment were sampled this year.

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CROP PHYSIOLOGY SECTION

By D. J. Watson

Investigations on Roots

Dr. Humphries has continued the work on the physiology of roots which he began in 1947. This has so far been mainly concerned with nutrient absorption. Experiments have been carried out to measure the uptake of N, P and K by excised roots from plants grown under conditions of controlled nutrient supply. The earlier experiments measured only the net gain or loss of ions over a 24-hour period and showed that roots deficient in a particular element would absorb that element when excised and placed in a complete nutrient solution in standard conditions of temperature and aeration. In later experiments the changes in mineral content of excised roots were followed at intervals of a few hours through a 24-hour period. It was hoped that these experiments would furnish data on which to base a standard procedure involving a less laborious routine for comparing the activity of root systems from plants grown in different conditions. It was found that the trend of the absorption curve depended on the magnitude of the initial deficit, and varied in different species, but the amount of an ion absorbed in a 24-hour period increased almost linearly with decrease in the concentration initially present in the roots. Further experiments to test a wider range of deficiency conditions are in progress.

The effect of carbohydrate content of the roots on nutrient uptake is being investigated by comparing roots from plants kept in the dark or in the light for a period before the roots are detached. In these experiments the respiration rate of the roots during the absorption period is being followed.

The experiments involve large numbers of estimations of nutrient content, and to speed up the analyses of a flame photometer is being constructed for the determination of potassium and other elements.

Dr. Watson was away until early June on a visit to Australia and America made possible by the grant of a travelling research fellowship by the Ministry of Agriculture. He spent about five months at the Waite Agricultural Research Institute In Adelaide, working in the Agronomy Department on zinc deficiency, and visited other research institutes in Western Australia, Victoria, New South Wales and New Zealand. Later he travelled for about three months in the United States and visited a number of the State Experiment Stations and Universities, mainly for the purpose of seeing recent developments in equipment and technique for research on botanical and plant physiological problems.

On 1st October 1948, the Crop Physiology Section was merged with the Botany Department.

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STATISTICS DEPARTMENT

By F. YATES

During 1948 the department has chiefly been concerned in the design and analysis of experiments, both for Rothamsted and other research stations and for the National Agricultural Advisory Service, and in the organization, supervision and analysis of agricultural surveys.

Two major surveys were carried out in the course of the year; the first was the Rapid Survey of Fertilizer Practice, which was carried out in five counties. This was undertaken in order to investigate the extent of the reported shortages of fertilizer supplies which had developed as a result of the increased use of fertilizers and the exceptionally early season. The second was the Survey of Maincrop Potatoes. This was undertaken by all provinces with the object of obtaining detailed information on the agricultural practices followed in the growing of potatoes, and also to test out whether any method of estimation of the yield of the potato crop was practicable. A pilot survey of the conditions under which milk is produced on farms has also been commenced, and results from one county, Wiltshire, are at present being analysed.

DESIGN AND ANALYSIS OF EXPERIMENTS

The volume of work on the design and analysis of experiments has been very considerable. The National Agricultural Advisory Services are now making considerable use of the department and Dr. Boyd has paid many visits to the various provincial centres in order to discuss various problems of experimental design on the spot. He is a member of a number of Provincial Field Experiments Committees and other Committees at National Agricultural Advisory Service Headquarters (46).

The design of the Rothamsted long-term experiment on the effects of various arable ley rotations was completed in conjunction with the other departments concerned, and the experiment has now been started. One part of this experiment will replace the Royal Agricultural Society of England Grazing Experiment which has now ended, and the other will be laid out on old arable land.

In addition to the design and analysis of the current year's experiments at Rothamsted, the work of summarizing the experimental results of the war years has been continued, and Mr. H. D. Patterson carried out an analysis of the results of the three-course rotation experiment.

Various pieces of work in experimental design and analysis have been carried out for the National Institute for Research in Dairying and for the Veterinary Laboratory, New Haw, Weybridge. Mr. Healy designed a series of experiments on minor element deficiencies in the Fen soils which were carried out by Mr. C. Barclay. The analysis of these experiments has also been carried out here. Mr. C. P. Cox, who was working on an agricultural research scholarship here last year, has now been appointed statistician at the National Institute for Research in Dairying and will be taking up his duties there as soon as their new building is completed.

Mr. P. M. Grundy has carried out some research into restricted types of randomization which allow the more unfavourable random

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patterns to be excluded without invalidating the estimation of error which can be derived from the experimental results. The problem first arose in connection with the types of design known as the "quasi-Latin square".

Dr. Yates prepared a paper on long-term rotation experiments for the Commonwealth Agricultural Bureaux Conference on Tropical and Sub-Tropical Soils (40).

Survey of Fertilizer Practice

A rapid survey was undertaken in the spring of 1948 in response to a request from the Ministry of Agriculture and the Agricultural Improvement Council to ascertain whether the reported shortages of fertilizer supplies were in fact serious, and to what extent they were likely to affect agricultural production. The survey was carried out in East Shropshire, West Warwickshire, the Taunton area of Somerset, the Hailsham area of East Sussex and the Vale of York. These areas were chosen partly because staff were there available for immediate execution of a survey, and partly in order to obtain as diverse a sample as possible of various types of farming in different parts of the country. The survey showed conclusively that although in certain small districts there were serious shortages at critical times, their extent was more limited than reports had indicated. The total effect on the agricultural production of the country as a whole is not likely to have been serious. The survey was noteworthy in that it proved possible to carry it out considerably more rapidly than any previous agricultural survey of a similar nature. The first request for the survey was made in April and a report was issued on the results in August (43).

This survey was not only valuable for its original purpose but also served to provide evidence on the changes of fertilizer practice that have occurred in the last two or three years. This information on current levels of use of fertilizers proved of considerable value in connection with the national plans for expanded agricultural production (see below). The current levels of nitrogenous manuring are shown in the following table. The large amount of nitrogen used on grass in East Shropshire is particularly noteworthy.

Use of Nitrogen on Farms in 1948

	Percentage of acreage dressed			Average rates of application on dressed acreage (cwt. N per acre)		
	Arable districts		Grassland districts	Arable districts		Grassland districts
	East Salop	West Riding	(mean)	East Salop	West Riding	(mean)
Cereals	60	40	43	·36	·23	·22
Potatoes	100	95	83	·84	·80	·68
Sugar Beet	97	100	—	1·06	·75	—
Mangolds	100	96	74	·96	·60	·56
Swedes	83	81	—	·60	·56	—
Hay: seeds	66	18	12	·42	·33	·29
meadow	68	25	9	·37	·20	·25
Pasture: ley	55	7	24	·35	·15	·35
permanent	27	8	8	·29	·25	·18

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During the year the field work of a routine survey was carried out in Berkshire, and the analyses were completed and reports issued on 7 further counties (48). 12 reports were also revised for reproduction by the Ministry.

Survey of Maincrop Potatoes

This survey was organized at the request of the Agricultural Improvement Council, and has been carried out by the officers of the National Agricultural Advisory Service. It has been designed to furnish comprehensive and precise information on the agricultural practices followed in growing maincrop potatoes, including cultivations, manuring, varieties, source of seed, pests, diseases, etc.

A further important feature of the survey is the testing of a simple and rapid method of estimating the yield of the potato crop. Work on the sampling of the potato crop by digging up and weighing short lengths of row as late as possible before lifting had been carried out by this department in conjunction with other departments and the farm in previous years, but no large-scale test under practical commercial conditions had been made.

Work was carried out by all the provinces in 1948. In some provinces the work was limited to certain counties, in others all the counties were covered, usually with a lower intensity of sampling. The farms were selected on the basis of their proposed potato acreages for 1948, a greater proportion of the farms with the larger acreages being taken. Within the acreage groups the selection was random. Two visits were made to all the selected farms and a third visit was also made to a sub-sample of these farms. At the first visit in June the agricultural particulars were obtained. At the second visit the selected fields were sampled for yield by taking 4 sample lengths of row (7 ft. each) randomly located in the field. At the third visit (to a sub-sample of the farms) samples were taken to determine the quantity of potatoes left in the ground after lifting. Particulars on date and method of lifting and the farmer's estimate of the total yield were obtained for all sampled fields. In a number of districts the sample fields were also examined for pests and diseases by the Advisory Staffs.

The results of the survey are at present being analysed. A preliminary report on yield was issued in October (44).

The experience of the 1948 survey has indicated that estimates of yield by sampling methods are likely to be practicable, and considerably more reliable than the estimates currently obtained. It is proposed to repeat the survey in 1949 and it is hoped that it will be possible to make the first test of methods of forecasting the yield a month or so before lifting time by taking weighed samples of the growing potatoes. Preliminary tests of this method of forecasting have already been made at Rothamsted and elsewhere with promising results, but the method must be tested on a larger scale over a number of years before any final conclusions as to its reliability and practicability can be drawn.

Survey of Methods of Milk Production

The main object of this Survey, which was planned by the Field Experiments Committee of the Agricultural Improvement Council, is to investigate the conditions under which milk is produced, so as to

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see in what directions improvement is required, and what advice should be given to farmers. The survey will also serve to provide an assessment of the equipment which is actually available on farms of various types for the production of milk.

The pilot survey referred to in the 1947 report has now been commenced, and results from one county, Wiltshire, are at present being analysed. The survey is being undertaken in three other counties, Hertfordshire, Caernarvon and Pembroke.

Textbook on Sampling Methods in Censuses and Surveys

The textbook on sampling methods for censuses and surveys was completed during the course of the year, and the printing was well advanced by the end of the year. The preparation of the book involved a good deal more research into methodology than had originally been anticipated. Opportunity was taken to review the whole of the subject and to develop the theory where this appeared to be required. It is hoped that the book will provide a standard textbook which will enable those who are not highly trained in mathematical statistics to plan sampling surveys with full efficiency (36).

Other Work on Sampling

Some work was carried out by Dr. Boyd on the sampling errors arising in the sampling of soils for chemical analysis to determine fertilizer requirements (47).

Mr. Read made an examination of the accumulated results of the sampling observations on the growth of wheat accumulated before the war under the Agricultural Meteorological Scheme.

Advice has been given to the East Midland Province on the design of a survey of poultry flocks. This survey is now in progress, and assistance may be required in the analysis.

A common method of sampling when samples are taken from the same universe on successive occasions is to replace part of the sample on each occasion by a fresh sample. The problems of estimation to which this method of sampling gives rise, have been investigated by Mr. H. D. Patterson (38).

Dr. Yates attended the 2nd Session of the United Nations Sub-Commission on Sampling which was held at Geneva.

National Plans for Increased Agricultural Productivity

A memorandum was prepared at the request of the Imports Substitution Panel on the best ways of utilizing limited supplies of additional nitrogenous fertilizer for increased agricultural productivity (49). This involved an analysis of the responses of grassland to nitrogenous manuring, similar to that already carried out for arable crops during the war. It was shown that very considerable increases in the productivity of grassland may be expected from the use of moderate dressings of nitrogenous fertilizer, and also that experimental results indicated that large responses might be expected to heavy dressings of nitrogen when grassland is used intensively for the production of dried grass and silage.

This work formed the basis of a paper presented at a meeting of the Agricultural Education Association on the relative yields of different crops in terms of food and their responses to fertilizers (41).

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Colonial Work

The department has continued to be consulted by many colonial research workers on problems arising in the design and analysis of experiments and on other experimental and sampling work. Mr. Healy carried out an analysis of a long-term coffee experiment from Tanganyika, and Mr. Church has been working on problems arising in the sampling of mealybugs—the vector of the virus causing "Swollen Shoot"—for the West African Cacao Research Station.

Assessment of Yields of Grass Pasture by Grass-cutting Techniques

No further field work was carried out at Rothamsted during 1948, but a paper has been prepared on the work of the previous three years (37). A further report was also prepared for the Joint Supervisory Committee on Ley Farming, which originated the work (46). The Committee has now been disbanded and further work on the same lines will be undertaken under the auspices of the Grassland Improvement Station.

Plant Breeding

Dr. Yates attended the 8th International Congress of Genetics at Stockholm and the Pre-Congress tour of the Plant Breeding Institute at South Sweden. He also gave a paper at the Conference of Plant Breeders held at the John Innes Horticultural Institute. He has been co-operating with the National Institute of Agricultural Botany in the planning of the future programme of variety trials.

Resazurin Research Scheme

The report on this work was completed in the course of the year by Mr. Eddison, working in conjunction with the National Institute for Research in Dairying. Statistical problems arising in any further investigations under the scheme will be handled by Mr. Cox.

Entomology and Parasitology

Mr. Dyke has succeeded Mr. Anscombe as statistical adviser to the Advisory Entomologists. The scheme of observations on certain important pest insects ("calendar insects") has continued and it is intended to undertake an analysis of the accumulated results during the coming year. Various items of work have also been undertaken for other departments at Rothamsted. Mr. D. R. Read has completed a paper in conjunction with Dr. P. H. Gregory on the spread of virus infection by aphids (39).

Hollerith Equipment

During the year the department has had the use of a sorter-counter and arrangements have been completed for the installation of a rolling total tabulator and the replacement of the sorter-counter by a sorter. Installation of this equipment is promised for June, 1949. This equipment should not only facilitate the analysis of all survey data but will also enable research to be carried out on the possibilities of handling more complicated analyses of experimental data—particularly experiments in which observations are made on a large number of variables—on punched card equipment.

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STAFF

The following appointments were made in the course of the year: Mr. G. M. Jolly (October, 1948), from Edinburgh University (Department of Agriculture Scholar); Miss E. P. Poulton (October, 1948), from Oxford University (Ministry of Agriculture Scholar); Miss M. A. Creasy (October, 1948), from University College, London.

The following members left to take up appointments: Dr. R. O. Cashen (September, 1948), Admiralty; Mr. R. T. Eddison (July, 1948), British Iron and Steel Research Association; Mr. D. R. Read (November, 1948), Research Department, Distillers Co. Ltd.

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PLANT PATHOLOGY DEPARTMENT

By F. C. Bawden

Dr. S. D. Garrett left in February to work on Panama Disease of banana in Jamaica and Dr. P. H. Gregory, who has worked in the Department since 1940 as a Research Officer of the Agricultural Research Council, was appointed in his place. To continue the work on potato virus diseases, Mr. T. W. Tinsley joined the staff in June. Mr. Salt replaced Miss B. M. Hawkey for work on *Cercosporella herpotrichoides* and Mr. Gates was appointed in August to work on sugar beet diseases at Hackthorn.

Dr. M. A. Watson returned in June from a year's leave of absence spent partly at the Waite Agricultural Research Institute at Adelaide and partly visiting Research Stations in Australia and the United States. At the invitation of the Centre National de la Recherche Scientifique, Mr. F. C. Bawden attended a Conference in Paris on Les unités biologiques douées de continuité génétique, and Dr. L. Broadbent attended the International Congress of Entomology in Stockholm.

Messrs. K. S. Bhargava, L. Broadbent and R. P. Chaudhuri were awarded Ph.D. degrees of London University.

Viruses and Virus Diseases

Laboratory and glass-house work

The main lines of work described in previous reports on the physio-chemical and serological properties of viruses were all continued. The electron microscope was completely overhauled and, with the acquisition of a shadow-casting apparatus, the quality of pictures obtained has been greatly improved. The method by which mounts are prepared greatly affects the manner in which particles of tobacco mosaic virus orientate and the type of picture obtained. The rod-shaped particles of potato virus X appear less rigid than those of tobacco mosaic virus and all methods of purification tried caused them to become entangled. Studies on preparations of virus X partially hydrolysed by trypsin gave no indication that hydrolysis disrupts the particles to produce rods of decreasing lengths. Preliminary work in conjunction with the Soil Microbiology Department on the bacteriophages that attack *Rhizobium* sp. suggests that some, but not all, forms occur with tail-like appendages similar to those described with certain other bacterial viruses.

With the Biochemistry Department work was continued in an attempt to gain further information on the relation between the crystallizable nucleoprotein obtainable from plants infected with the Rothamsted culture of tobacco necrosis virus and the infective particles. The crystallizable material has smaller particles than any other virus (about 17 mμ diameter), but the infective particles may be larger as they sediment more readily. The manner in which extracts of infected plants are made influences the ratio of infective to non-infective material, but consistent results have not yet been achieved.

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Outbreaks of a systemic necrotic disease in tulips were diagnosed as resulting from infections with various tobacco necrosis viruses (67). This is the first host encountered in which these viruses seem to become fully systemic, but a lethal disease in French bean, known in Holland as stipplestreak, was also identified as caused by a tobacco necrosis virus related to the Rothamsted culture.

Tobacco veinal necrosis virus was found by serological tests to be related to potato virus Y, but unlike other viruses that share antigens, these two were not mutually antagonistic when present together in the same plant.

Studies were made on the ratios with which tobacco mosaic and tomato bushy stunt viruses combine with albumin when heated with it under various conditions; complexes that contained three or more times as much albumin as bushy stunt virus still combined with virus antiserum but were not precipitated by it (70).

Results from work on the yellowing disease in Family 41 sugar beet did not support the claim of workers in Eire that it is caused by a strain of sugar beet yellows virus that is seed-transmitted in this family. The cause was only with difficulty transmitted by aphides and produced less generalized symptoms than those caused by sugar beet yellows virus; it did not protect plants against the latter or react with antiserum to yellows virus. It seems possible that this is a distinct disease that may have arisen in this genotype.

Sugar beet yellows was transmitted for the first time by inoculation with sap from diseased plants (68). Shading plants after infection by aphides both delayed the appearance and reduced the severity of symptoms. Also, when fully infected plants were shaded, they produced new leaves much less yellowed than those produced by control plants.

The frequency distribution of local lesions caused by certain viruses was analysed and found to be skew, so that statistical tests of significance should not be directly applied to them (69).

Evidence was obtained that water-culture solutions in which roots of infected plants were growing could become infective. The addition of sap containing virus X, tobacco mosaic or tomato bushy stunt viruses, to soil in which tomato plants were growing produced infections of roots with all three viruses. In most plants the viruses were confined to the roots, the leaves and stems remaining virus-free; passage of virus into aerial parts occurred more frequently when plants were cut back so that new side shoots developed.

Experiments on the effect of fertilizers on the susceptibility of tobacco plants to tobacco mosaic virus were continued. Using sand cultures, N, P and K, affected virus multiplication in the same way as with plants growing in soil, but increasing nitrogen increased susceptibility to infection (as measured by local-lesion counts) more in sand than in soil.

Field work

Field experiments and observations on commercial crops were continued to gain information on the epidemiology of potato and sugar beet virus diseases, and were also extended to lettuce mosaic.

Close topping of mangolds reduced the spring infestation of *Myzus persicae* on clamped mangolds, but not of *Hyperomyzus*

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staphyleae, which successfully colonizes roots. Blowing derris powder on to roots at time of clamping did not reduce infestation. The survival of *H.staphyleae* is less important, for it is apparently unable to transmit sugar beet yellows or mosaic. A new over-wintering host for *M.persicae*, an ornamental almond hybrid, *Prunus Amygdalus-persicae*, was identified. Eggs laid on this hatched and produced large infestations in spring. No evidence was obtained than aphides use any olfactory sense to find their winter host; nor were flying aphides attracted by other *M.persicae* or by honey-dew. Having found the host, apparently by chance, winged aphides tend to associate in groups.

Work is continuing on the effects of micro-climate on aphid multiplication and movement; results of experiments to test the frequency with which winged *M.persicae* fly under various conditions (58) show that changes within crops are adequate to influence mobility and consequent likelihood of spreading viruses.

Results are not yet complete on experiments made with potatoes to study the effects on aphid population and virus spread of varying such factors as water and nutrient supply, date of planting and time when exposed. Records were also made of the manner in which fumigated plots became re-infested with *M.persicae* and of the relative abundance of the aphid on different susceptible hosts through the summer.

The effect of roguing to prevent spread of leaf roll and rugose mosaic was again tested; results of tests in 1947 agreed with those from earlier work (60), in showing that roguing needs to be done by the first week in July with Majestic and earlier with Arran Pilot to produce any significant result.

Work at Hackthorn largely dealt with developing control methods against sugar beet yellows. Steckling beds in areas which produced healthy plants in previous years were heavily infected in 1947–48. An experiment was made to test beds in counties relatively free from sugar beet and mangolds and known to be favourable for seed-potato production. A number of methods of clamping stecklings was tested and the only failure was with a cover of loose straw, when the plants became dry and were attacked by mice. Better stands of seed plants were obtained with clamped stecklings raised in Berwickshire than with those out-wintered there. There was no evidence that plants deteriorated when stored three weeks between transport and planting, although the stands were poorer in the later plantings because of drier and more unfavourable soil conditions. Different planting times were tested and yield data have been obtained, but the most important result was the demonstration that *Myzus persicae* over-wintered on plants out-wintered and grown on without transplanting. Large populations developed on these plants in May, but not on those transplanted.

The number of infected plants was reduced and yield increased by sowing stecklings in April in a cover crop of barley compared with July sowing in a nursery bed. Delaying sowing until late August also reduced incidence of yellows and increased yield of seed.

In a field experiment to compare isolates of yellows virus that consistently produce either mild or severe symptoms under glass, all isolates produced similar severe symptoms. Further experiments

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are being made to elucidate the differences in symptoms in the two conditions.

Field counts and aphid trapping, such as were done intensively in recent years, were continued on a much reduced scale in 1948. Local surveys have been undertaken in the Hackthorn area at intervals throughout the year, but the results have not yet been analysed. Beet fields have been examined near seed crops and a survey of mangold clamps by the Sugar Corporation staff was organized and associated with field counts of disease infection in sugar beet. The incidence of yellows in root crops in June was closely related to proximity of mangold clamps and seed crops.

In a field experiment at Woburn, both the number of sugar beet plants becoming infected with yellows and the size of aphis infestation were found to be approximately a constant per unit area. Doubling the plant population approximately halved the percentage of the crop that became infected. Observations on irrigated sugar beet at Milford, Surrey, showed no effects of irrigation on either aphid population or incidence of virus disease.

Experiments and observations on lettuce at Taplow, Bucks., showed that *Myzus persicae*, *Nasonovia ribicola* and *Macrosiphum euphorbiae* were the most common pests, and of these *M.persicae* is the important vector of lettuce mosaic. Over-wintering crops were most severely affected by mosaic, many being rendered worthless. Young lettuce crops became infected by aphids migrating from older crops, which may also serve as sources of virus. Alternative sources, however, are also often provided by diseased plants within the crops arising from infected seed. Such seed-borne virus may account for 3 per cent. or more of the crop being initially infected. In crops well isolated from other lettuce, infected seed is probably the chief cause of outbreaks, but spread from neighbouring diseased crops can lead to a high incidence in crops initially virus-free.

Mycology

Work was started to study the factors affecting the dispersal and deposition of spores, and a suitable wind tunnel for this was designed and is now being constructed. To supplement data from laboratory work, field work was started to study the deposition of spores on leaves and other surfaces and their dispersal by wind up to distances of 1 metre from the point of liberation. There has been little previous work on this subject, and the main object is to study factors determining the number of spores deposited per unit area from a volume of air containing a known spore load. This information is needed for a better understanding of the first stages of infection of plants by spores, for predicting disease gradients and for interpreting data on the numbers of spores caught on sticky traps. As yet only vertical traps have been tested; the number of spores caught per unit area increases as the size of trap is reduced, and, except with very small traps, only a small proportion of spores in the air subtended by the trap is deposited.

Experiments on eyespot of wheat (*Cercosporella herpotrichoides*) were continued, and a severe attack of take-all (*Ophiobolus graminis*) introduced an additional factor to those planned for the last year of the experiment in Little Knott. Spraying with H_2SO_4 was

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again highly beneficial; it reduced the area infested with weeds from 76 to 14 per cent. and the area lodged from 59 to 20 per cent., but was without effect on take-all. For the first time, spraying increased straw (by 17·6 cwt. per acre) and it also increased grain by 7·3 cwt. per acre. Addition of 2 and 4 cwt. of ammonium sulphate per acre reduced the area affected by take-all from 54 to 26 and 13 per cent. respectively. Nitrogen increased the proportion of crop that became lodged and increased yield only on acid-sprayed plots which did not become lodged.

Increasing rate of seeding from 1·5 to 2·8 and 3·5 bushels per acre, increased the area affected by take-all, which prevented any increased lodging such as occurred in previous years. Rate of seeding had little effect on yield, but the lowest rate gave the highest yield. The worst plots were those which were unsprayed, received no nitrogen and largest seed rate; these were weedy and had much take-all and gave a grain yield of only 11·7 cwt. per acre. Lower seed rate, combined with spraying and addition of nitrogen, reduced weeds and take-all and increased yield to 29·1 cwt. per acre.

Experiments out-of-doors with plants in pots showed that severity of eyespot was much reduced by adding ammonium sulphate to both ordinary field soil and soil rich in organic matter. Phosphate, on the other hand, in the presence of lime increased the severity of eyespot and decreased yield. In plants grown in sand cultures, the loss of yield caused by eyespot was decreased by addition of N, P and K, N being most effective in reducing loss and P least effective.

The survival of *Plasmodiophora brassicæ*, the cause of club root in cruciferous plants, was studied under various crops and in fallow. Boxes of infested soil were sown with cabbage, kale, *Lepidium sativum*, *Matthiola incana*, *M.bicornis*, *Papaver rhoeas*, *Tropæolum majus*, bean and onion, and after three months, survival was tested by the method of counting infected root hairs described by Samuel and Garrett. Susceptible crops were removed before decay of the clubs had begun. Infection-counts after cruciferous crops were lower than after non-crucifers (except *Papaver*). After *Papaver*, infection-count figures were comparable to those obtained after crucifers, but this requires to be repeated on a larger scale. Survival in fallow soil appeared to be affected by the addition of fertilizers as judged by the infection count on cabbage seedlings. After soil samples had been taken for the infected root hair test, the various crops were removed and cabbage sown in every box. 90–100 per cent. of these plants developed club root after all types of crop, in spite of differences in root hair infection.

Contrary to frequent reports in the literature, *Lepidium sativum* was found to be susceptible, more than 90 per cent. of the plants becoming affected. Tap roots showed only slight swellings and there were only a few small galls on lateral roots, although the roots contained plasmodia and resting spores. Marrow stem kale plants were all severely clubbed and one systemically infected plant was found, much dwarfed and distorted. Neither species of *Matthiola* formed clubs, nor could any plasmodia or resting spores be seen in sections of the root, although the root hairs were infected and contained zoosporangia. This suggests a difference in pathogenicity

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between the stage found in root hairs and that usually associated with clubbed roots.

Zoosporangia, indistinguishable from those of *P. brassicæ*, have been found in the roots of many non-cruciferous plants and zoospores have been seen discharged from the root hairs of *P. rhoeas*. Infection experiments have provided convincing evidence that *P. brassicæ* can infect and form zoosporangia in the root hairs of: *Papaver rhoeas, Tropæolum majus, Reseda odorata, Lolium perenne, Agrostis alba stolonifera, Dactylis glomerata*. No other recognizable stages of *Plasmodiophora* have been seen in the roots of these plants, and their importance in the epidemiology of club root remains uncertain. The root hairs of wheat, oats, rye, barley and maize, when grown under identical conditions, were not infected.

Differences in root-hair infections in different soils, in which the proportion of plants clubbed and the severity of the disease were all the same, prompted experiments on the relation between the number of spores in the soil, the number of root hair infections (measured after seven days), percentage of plants clubbed and severity of attack. Results are still incomplete, but it seems that the minimum number of infections associated with club formation is small, probably under ten. Cabbage stems were infected with *P. brassicæ* through needle wounds as described by Larson (1934), and this led to the formation of cortical galls and cambial invasion, the pathogen migrating up the stem and causing proliferation of axillary buds. Tissue removed from such stems was grafted to healthy stems which, several weeks later when stock and scion were united, began to swell into a large gall, indicating cambial invasion. This was followed by invasion and expansion of axillary buds above and below the graft.

Work was begun on seedling diseases of sugar beet which are becoming increasingly prevalent, presumably because of the lower plant populations now obtained with the common practice of early sowing. Better stands were obtained by treating seed with an organo-mercury dressing by the "short-wet" method than by treatment with another organo-mercury powder. The beneficial effect was most pronounced with seed heavily infected with *Phoma betæ*.

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BIOCHEMISTRY DEPARTMENT

By N. W. Pirie

Our work on the enzymic decomposition of leaf fibre has been co-ordinated during the year and we hope soon to be able to publish a comprehensive report on the carbohydrases that are involved, and on the factors that influence their action.

Analytical Methods

The development of methods of analysis suitable for application to enzymic digests of leaf fibre has been continued by Tracey. The rapid method for the determination of uronic acids reported on last year has proved satisfactory. A colorimetric method for the estimation of pentoses in the presence of large amounts of hexose and uronic acids has been developed and is now in use. It has been found that the pentose content of tobacco fibre is low—about 2 per cent. of the dry weight. He hopes to develop a method for the estimation of galactose in the presence of large quantities of glacturonic acid. If this is successful it should be possible to obtain figures for all the sugars present in enzymic digests of leaf fibre, and. as a consequence, perhaps, understand better the action of the snail enzymes in liberating virus from fibre.

The enzymes present in the digestive juices of the snail have been further studied both with regard to the range of substrates they are able to attack and to their activity on individual substrates. Tracey has developed a very sensitive method for the estimation of small quantities of cellulase, based on measuring the reduction in viscosity of a soluble cellulose derivative by the enzyme. Even with this method, which can detect a 1 in 100,000 dilution of snail digestive juice, no cellulase activity has been demonstrated in leaf extracts or leaf fibre.

Kinetics of Carbohydrases

M. Holden has continued to work on the effect of salivary amylase, trypsin, purified polygalacturonase, the digestive juice of the snail, *Helix aspersa*, and a number of fungal extracts on leaf fibre. The extract from *Aspergillus aureus* and two commercial enzyme preparations Pectinol 10M and Enzyme 19AP (Rohm and Haas) are as effective as snail digestive juice in breaking up the fibre and releasing soluble carbohydrate material. Factors, such as pH, concentration of salts, and concentrations of enzyme and substrate, affecting the rate and extent of the action of the various enzymes, have been studied. Fine grinding of the fibre in the triple roller mill, before incubation with enzymes, was found to increase the rate of action of the enzymes but made little difference to the total amount of carbohydrate liberated. Removal of calcium from fibre greatly increased the rate of action of snail digestive juice and fungal enzymes. With purified polygalacturonase on decalcified fibre an increase in the total amount of carbohydrate liberated was found. Up to 80 per cent. of the fibre calcium can be removed by treatment at pH5 with an acetate-ammonium chloride solution. Extraction at pH 3 does not increase the amount removed but almost all the calcium remaining after the salt treatment can be brought out by extracting with 0·05N HCl.

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Oxidation of Manganese by Plant Extracts in the Presence of H_2O_2

Manganese apparently plays a part in plant respiration. Lundegardh found that the O_2 uptake of Mn deficient wheat roots was raised by 155–470 per cent. by the addition of 5×10^{-5} M. $MnCl_2$. Such an effect might be brought about by a system in which the Mn undergoes alternate oxidation and reduction. Satisfactory evidence has been put forward that Mn is oxidized in the higher plants; it can also be oxidized by soil micro-organisms (Mann, P. J. G. and Quastel, J. H.—1946, Nature, **158**, 154).

In preliminary investigations of the distribution of Mn in the plant, Kenton and Mann have obtained evidence that Mn is oxidized by certain plant extracts in the presence of H_2O_2. During the year an investigation of the system has been made with the following results:—

(1) A system which brings about the oxidation of Mn in the presence of H_2O_2 has been demonstrated in horseradish root extracts. Evidence has been obtained that this system exists in other root extracts.

(2) Suitable conditions (i.e. in pyrophosphate or citrate at pH 7) colorimetric evidence has been obtained that the oxidized Mn can be accumulated as a coloured manganic complex. In the case of the horseradish root extract, MnO_2 was isolated by the dismutation of the manganipyrophosphate at weakly alkaline reaction. The oxidation product decomposes N_2H_4 and manometric estimation of the oxidation product have been made by means of this reaction.

(3) Further evidence that Mn oxidation takes place has been obtained by demonstrating an increase in the catalase activity of horseradish extract by the addition of $MnSO_4$. A definite increase in the catalase activity could be demonstrated by the addition of 2·2 μg. Mn.

(4) Studies of the effect of heat, pH, inhibitors, and H_2O_2 concentration have been made. The results suggest that an enzyme is involved. The system is insensitive to low concentrations of cyanide, otherwise the results support the view that the enzyme is a peroxidase. In addition another factor may be necessary.

(5) The hypothesis is put forward that a Mn oxidation-reduction cycle is responsible for the effect of Mn on plant respiration.

The effect of Cu on Mn oxidation in the soil

Lees obtained evidence that Cu is necessary for nitrification in soils. In soils treated with Cu-enzyme poisons e.g. diethyldithiocarbamate, nitrification was inhibited and could be restored by the addition of small amounts of $CuSO_4$. Using the same technique a similar effect of Cu has been shown on Mn oxidation by soils. The partial reactivation of diethyldithiocarbamate inhibited soils has been demonstrated with very low $CuSO_4$ concentrations.

The easily reducible Mn of organic soils

Heintze and Mann have continued their work on the problem of Mn deficiency and have put forward the hypothesis that such

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deficiency occurring on neutral and alkaline soils of high organic matter content and of adequate total Mn content is due to the formation of complexes of divalent Mn with the organic matter which are dissociated to such a slight extent that the Mn in the soil solution is insufficient for the needs of the plant.

The easily reducible Mn (extracted by N. NH_4 acetate containing 0·2 per cent. hydroquinone) forms a much smaller part of the total soil Mn than is the case with mineral soils of low organic matter content. Preliminary results indicate that this is due not to the presence of the Mn in forms resistant to reduction, but, at least in part, to retention by the soil organic matter of the divalent Mn produced on reduction.

The Study of Tobacco Necrosis Virus

This virus has been under more or less continuous investigation by Bawden and Pirie since 1941, but it still proves perplexing. Using a standard method of purification, two or three cycles of ultracentrifugation, and low speed centrifugal clarification, preparations have been made from leaves subjected to a wide range of pre-treatments and the infectivity and chemical, physical, and serological properties of the products have been compared. The age of the infected leaf and the duration of infection do not have a great influence. The conditions under which the leaf, after removal from the plant, and the sap are kept do, on the other hand, exert a large influence. In the leaf most treatments e.g. freezing, wilting and exposure to chloroform vapour, tend to inactivate the virus. In the sap ageing for a few days or freezing or exposure to chloroform cause an activation. This effect is partly due to the removal of unstable normal proteins but our results cannot be explained purely on the basis of dilution of the final preparations to different extents by normal proteins. All infective preparations contain at least three distinct substances, the infective virus, a serologically active sedimentable nucleoprotein that is either a derivative of the virus or a product of the deranged metabolism of the infected leaf, the normal sedimentable nucleoprotein which can also be made from uninfected leaves. An attempt is being made to define the relationship of these substances to one another.

Proteins of normal leaves

All virus preparations are to some extent contaminated with normal leaf protein and these proteins have been investigated from time to time during the last decade. The most interesting is a nucleoprotein with a sedimentation constant in the same range as the viruses which occurs to the extent of 1–2 g per 1 in sap from young leaves. The preparation of those viruses that give small yields is only possible because older leaves, and especially leaves that have matured as a result of virus infection, contain much less of this protein and because it is less stable than the viruses with which we work and dissociates into an insoluble part and an unsedimentable part during rigorous purification. Its properties are being studied in the hope that a convenient method of recognising it as a contaminant of virus preparations may be discovered.

During this year a start has been made on the preparation of leaf protein on a technical scale. Several mills suitable for grinding fresh leaves at about a ton an hour have been tested and the most

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suitable will be installed and operated at the Grassland Improvement Station during 1948. In general the performance of a full sized mill has to be tested, it cannot be deduced from laboratory tests. Stamping mills are an exception and Tracey has measured the amount of work needed to liberate sap from grass and other leaves by impact. Liberation is satisfactory with the expenditure of about 10 horse-power for a ton an hour grinding rate.

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NEMATOLOGY DEPARTMENT

By T. Goodey

Our first year as a department of Rothamsted has, of necessity, been a broken one as we continued in our old quarters at Winches Farm, St. Albans, until the transfer to Rothamsted Experimental Station which was carried out at the end of June 1948. Work was naturally impeded by the impending removal, the uncertainty of the date of the latter and also by the disturbance entailed in the move itself and the process of settling in. In spite of these adverse factors, valuable work has been carried out and some useful results obtained.

Early in the year Dr. Goodey prepared a report on his visit to the United States and Canada (May-September, 1947) and this was duly presented to the Ministry of Agriculture and to the Agricultural Research Council. As a British delegate appointed by the Royal Society, Dr. Goodey attended the 13th International Congress of Zoology held in Paris in July 1948, and delivered a lecture on Plant Parasitic Nematodes to the Section on Applied Zoology and Parasitology.

Although we were established in our new laboratories in July 1948, there was considerable delay before our greenhouses were erected and we could begin the digging and the laying-out of the area on which our experimental plots are to be established. By the middle of November, however, most of the ground had been dug, the lay-out of the plots determined and a few of them planted. These plots are to serve as the living museum of plant parasitic eelworms.

Research conducted in the department falls naturally into two main sections: (1) problems connected with plant infestations by species of the genera *Anguillulina* and *Aphelenchoides* and soil nematodes generally (Dr. T. Goodey, Dr. M. T. Franklin and Mr. J. B. Goodey); (2) those connected with *Heterodera* species (Dr. B. G. Peters and Mr. D. W. Fenwick).

Anguillulina and Aphelenchoides

Anguillulina

The stem eelworm, *Anguillulina dipsaci*, is probably best described as an aggregate species which can be roughly sub-divided into so-called biological races and a main line of work is directed towards the more precise definition and differentiation of these races. Fortunately a small quantity of infested material of Teasel, the type host, *Dipsacus fullonum*, from Oregon, was given to Dr. Goodey during his visit to the United States and this has provided a norm for comparative studies. It is now known that the eelworm disease of Teasel occurs in England and a native source of material has thus become available.

Some work has been done during the year on host transference of the teasel eelworm and certain other races such as the oat/onion/bean race, the narcissus, the red clover and the lucerne races. All of these appear able to transfer successfully to onion seedlings and to reproduce in them. On the other hand the oat/onion/bean race does not transfer to narcissus nor the red clover race to oats. The further implications of this work are being followed up.

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The eelworm causing tuber-rot of potatoes was shown by Thorne in 1945 to be a species distinct from the true stem eelworm, *A. dipsaci*, and the name *Ditylenchus destructor* was given to it. The same parasite attacks potato tubers in Great Britain and we have been studying it closely during the year. We have confirmed, by pot experiments, its ability to transfer to and cause necrotic lesions in the rhizomes of Corn Mint, *Mentha arvensis* L.; a host transference first found in Prince Edward Island. On visiting fields in the Fens where in 1947 potatoes were affected by the pest and in 1948 wheat was grown, Corn Mint was found as a common weed and in many plants examined necrosed areas were found on the rhizomes in which *Ditylenchus destructor* was found in all stages of development. The parasite was also found in similar necrotic areas on the rhizomes of another common weed, viz. Corn Sowthistle, *Sonchus arvensis* L., a new host record. A paper on these findings has been written and accepted for publication.

Several new weed hosts of the onion race of *A. dipsaci* have been discovered and an experiment attempting the control of the oat race on a field scale in its weed hosts is planned for next Spring.

Work is in progress on the eelworm infesting bulbous irises, the taxonomic and biological relationships of which have been very obscure and puzzling for many years. This work promises some most interesting results. In attempting the differentiation of the various biological races of *A. dipsaci* it became apparent that the conditions under which nematodes are killed and fixed needed standardization and work is in progress along these lines.

A. dipsaci in the living, quiescent condition can be seed-borne on onion, red clover and teasel seed and it was shown by Goodey in 1945 that infested onion seed could be successfully fumigated with methyl bromide with negligible effect on the germination of the seed. Further tests have been made with methyl bromide and we have found that in the case of red clover and teasel seed, fumigation is equally efficient and that there is no deleterious effect on the seed.

Work has been done on the detailed morphology of *Anguillulina* species which are often found associated with plant roots as parasites or partial parasites. A new species of the genus has been discovered and will shortly be described. A paper on the occurrence of phasmids (sensory papillae) on the male tails of three species of the genus has been written and will appear very shortly.

APHELENCHOIDES

Morphology and biology. Most of the work has been on strawberry nematodes, as more than one species seemed to be present. Strawberry plants with eelworms of the genus *Aphelenchoides* in the buds were received from about 10 places in England and Scotland. The nematodes were examined and in many cases drawn and measured and it became evident that two species were present, *Aphelenchoides fragariæ*, and what appeared to be *Aph. olesistus*; occasionally both were present on the same plant. They were differentiated by differences in width, position of the excretory pore and curvature of the male tail on killing by heat. Support for the identification of the second nematode as *Aph. olesistus* was given by an infection experiment: on four occasions the strawberry form was inoculated on to different fronds of *Pteris*, and in one case

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the nematodes successfully entered the tissues of the frond and typical 'leaf-blotch' symptoms appeared in 5–6 weeks. After 3 months the diseased patch was excised and teased up and about three times as many worms were found as had been used as an inoculum. No morphological differences could be found between *Aph. olesistus* from strawberry and those from violet and fern.

Culture of Aphelenchoides *species.* Making use of a maize-meal agar on which a growth of the fungus *Alternaria tenuis* is established certain species of *Aphelenchoides* can be successfully grown; usually at 24°C. Under these conditions *Aph. olesistus* from strawberry more than doubled its numbers in a month and many eggs were found. *Aph. fragariæ* on a similar medium also multiplied but not quite so vigorously. *Aph. ritzema-bosi* (the chrysanthemum foliar eelworm) maintained itself on agar but when inoculated into ripe tomato multiplied six-fold and spread throughout the fruit in 10 weeks. In a second tomato fruit the numbers doubled in 2 weeks. *Aph. olesistus* from infested leaves of *Lilium* sp. and *Aph. subtenuis* from narcissus were also established on agar plates along with the fungus *Alternaria tenuis*; the former multiplying to very large numbers. *Aph. olesistus* from violet was successfully transferred to *Pteris*, the nematodes increasing three-fold in about 9 weeks.

Using the same cultural technique the nematode, *Aphelenchus avenæ*, which may be a facultative parasite on plant roots, has been cultivated successfully; its feeding habits and the behaviour of the mouth spear have been studied under these conditions.

Staining technique. Dr. Franklin has developed a quick staining method for demonstrating eelworms in plant tissues. It is a modification of the acid fuchsin lactophenol technique. She has also done much work on a review of the genus *Heterodera* and the relevant literature, a genus on which she is an acknowledged authority.

Heterodera

That side of the department's work concerned with eelworms of the genus *Heterodera* has consisted largely in bringing to completion the Agricultural Research Council field trials on the nematocidal effects of D-D mixture, and in pursuing certain technical problems raised by those trials. The routine laboratory work on the final series of soil samples was completed in March, and a full report was then drawn up and submitted to the *ad hoc* Agricultural Research Council Committee on 30th April. On the recommendation of that Committee, the report has since been recast and expanded in a form suitable for publication and is now ready for the press.

The trials were carried out at seven 2-acre sites on sandy, silty, and blackland soils. Apart from a pilot trial where soil was injected in Spring, injections were carried out in the autumn, and potatoes were grown the following year. Factors investigated were rate of application (0, 200, 400 and 800 lb. D-D per acre), depth of injection (4 or 8 inches) and the effect of rolling after injection. At the most responsive of the sites (Wainfleet), yield, kill and the final eelworm population were all roughly proportional to the rate of application. Under favourable circumstances a 50 per cent. increase in yield and something like a 50 per cent. reduction in eelworm

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population can be expected from 800 lb. per acre, but the latter reduction is more than made good during the growth of the subsequent crop; accelerated multiplication of eelworm on the treated plots leads to their finally having a larger population than the untreated controls. Of the sites tested, the blackland soils gave a lower eelworm kill and a much lower yield increase from D-D than silts or sands. After autumn injection the nematocidal, and probably the phytocidal, effects of D-D persist in the soil for many weeks.

The counting of over a million cysts, eggs and larvæ, from upwards of 1400 soil samples collected during the trials, has left a large body of data, the statistical analysis of which was undertaken by Mr. G. V. Dyke of the Statistical Department. These data show that there are pronounced anomalies in the counts of larvæ "hatched" by the calcium hypochlorite technique. This technique has failed not merely to differentiate between living and dead larvæ, but even to give a reliable total count of the content of cysts. Accordingly, a detailed investigation of the technique has been undertaken, as a result of which it is now possible to secure a reliable total count. Some progress has also been made towards differentiating living from dead larvæ by the same technique, but at present it is doubtful whether results can ever compare with those of the lengthy root-diffusate technique. The latter is also under investigation with a view to improving the consistency of counts. Sigmoid curves have been obtained from plotting "percentage hatch" against "time" and these may prove amenable to probit analysis. Progress is necessarily slow since hatching requires some 8 weeks, and inherent variability necessitates large samples, but to date the hatch from 1,500 individual cysts has been separately counted at least weekly. Work on the dilution of root-diffusate is also in hand, and on its concentration by adsorption on animal charcoal followed by solution with 20 per cent. acetone and evaporation.

The nematocidal action of D-D mixture is also under investigation, both used neat in small pot experiments and in aqueous solutions. Solutions for nematocidal tests have also been prepared from fractions of D-D mixture volatilized at room temperature by passing measured volumes of air through it. The fractions are not homogeneous; the complete D-D is soluble in spirit, but, after volatilizing 9/10, the residual 1/10 is insoluble in spirit but soluble in acetone.

At the invitation of Mr. L. N. Staniland, who has found considerable nematocidal power in trichlorophenol (T.C.P.), tests are in hand on dilutions of this material. In these, and the previously mentioned tests, use is also being made of the vinegar eelworm as a convenient laboratory animal. The hypothesis, awaiting confirmation, is that substances with no effect on vinegar eelworm will also be without effect on encysted *Heterodera* larvæ. If this is confirmed it will give a rapid method for eliminating useless substances and/or concentrations; at present, many weeks are wasted in such elimination when using the root-diffusate technique. A modification of the McMaster counting slide enables eelworms in 1 ml. of liquid to be counted rapidly and with greater convenience than in the previously used solid watch glasses.

Experiments on the thermal death point of *H. rostochiensis* have been carried out in greater detail than hitherto; it is confirmed

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that damp cysts entail a lower lethal temperature than dry cysts. Extensive previously-collected data on larval lengths of different *Heterodera species* have been analysed and results are being prepared for publication.

The following joint investigations and contacts should be reported:

(1) The department is co-operating with the West Norfolk Farmers Co-operative and Messrs. Shell to investigate the effects of annually repeated injections of D-D mixture in infested potato soils. Data for this (the first) year have been analysed.

(2) The department plans co-operating with Dr. H. C. Gough of Cambridge in long-term investigations on eelworm population changes during different crop rotations in different soil types.

(3) Messrs. Seymour Cobley Ltd. have been advised on the warm-water treatment of seed potatoes to kill adherent *Heterodera* cysts: at present they prefer to carry out their own tests.

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ENTOMOLOGY DEPARTMENT

By C. B. Williams

During this period we have lost Dr. A. C. Evans who has gone to the Overseas Food Corporation in East Africa and Mr. W. J. Mc.L. Guild who took up an appointment at the University of Edinburgh. In addition Mr. S. N. Banerjee has returned to India after having been awarded the degree of Ph.D. at London University. Dr. F. Raw was appointed in August 1948 to replace Dr. A. C. Evans, and in May 1948 Mr. L. R. Taylor was appointed as an assistant Experimental Officer. Dr. H. F. Barnes represented the Experimental Station at the 9th International Congress of Entomology in Stockholm in August 1948.

Insect Ecology

Dr. Williams has continued his work on insect migration, on the relation of insects to weather conditions, and on the relative abundance of insects in wild populations.

During 1948 there was very little insect movement into this country from abroad, after very widespread immigration in 1947. There were no extended movements of *P. gamma* or of the Cabbage-White Butterfly (*P. brassicæ*), and damage done by these two pests was negligible. Records of insect migration continued to come in from all parts of the world.

During 1948 three light traps were in use continuously, including two that were working in 1947 and one new one in the garden at Rothamsted Lodge. The latter has turned out to be a very good location and large numbers of insects have been captured. The work on analysis of the relation of catches to weather conditions is proceeding.

The Lepidoptera in the light trap are being used also for the study of the structure of mixed insect populations, and the relative abundance of species. We now have one trap (A) with 7 years' catches (4 before the war and 3 since)—and three other traps for 3, 2 and 1 year, making a total of 13 trap years. The total number of Lepidoptera identified is about 60,000 belonging to 320 species. The frequency distribution, which follows closely to the logarithmic series is small samples, shows more indication of fitting to a log-normal distribution in large samples.

Many of the mathematical properties of the frequency distribution of insect species have been shown to apply to the distribution of plants.

Gall Midges

Dr. Barnes reports that this long-term study of the incidence of the two wheat blossom midges on Broadbalk was carried out for the twenty-second successive year. The predicted fall in total numbers of larvæ of both species continued as shown by the figures 33,491, 21,693 and 15,417 larvæ per 500 ears for the years 1946, 1947 and 1948. The corresponding grain infestations were 26·6%, 15·4% and 14·7%. When the two species involved are considered separately, it is seen that *C. tritici* numbers fell for the second successive year, while those of *S. mosellana* increased considerably.

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This increase was sufficient almost to maintain the percentage infestation by both species in spite of there being considerably more grain available for attack (per 500 ears) than in 1947. It should be remembered that *S. mosellana* larvæ are almost solitary whereas those of *C. tritici* are gregarious. It is thought that in 1949 or 1950 the numbers of these two midges will be at their lowest for the cycle and thereafter a rise in numbers will take place.

The year 1948 was a better year for the emergence of *S. mosellana* in the insectary than was 1947. More midges emerged from samples of larvæ collected in 1939, 1940, 1944, 1945 and 1946 than emerged from these samples in 1947; for example, twice as many emerged in 1948 from the 1945 samples and more than six times as many from the 1946 samples as in 1947. The emergences from the 1939 samples showed that under these conditions *S. mosellana* larvæ can stay nine winters after leaving the wheat ears before emerging as midges.

Dr. Barnes was successful in finding the larvæ of what must be the true *Contarinia nasturtii* Kieffer, popularly called the Swede Midge, infesting the flowers of one of its original wild host plants, *Rorippa amphibia*, at Bedford. He was successful in rearing the midges both from these flowers and similar ones obtained in Holland. He is attempting to build up a stock of these midges in order to try to establish whether the true *C. nasturtii* will, besides infesting the blossom buds of wild *Rorippa* and *Nasturtium* spp., cause leaf damage, (e.g. 'many-necked' and 'crumple-leaf' condition of swedes) on *Brassica* spp. It has been generally accepted in England that *C. nasturtii* does leaf damage to *Brassica*, but continental authorities maintain that a distinct species is involved. This problem was discussed thoroughly with the Dutch authorities during a visit to Holland in April, and with Danish and Swedish authorities during Dr. Barnes' visit to Denmark and Sweden in August. It is to be hoped that Dr. Barnes will soon be able to settle this point and also the further one concerning the possibility of the midge involved in the leaf damage being also responsible for *Brassica* flower damage.

Immunity and preference trials showed that the gall midge *Wachtliella ericina* F. Loew will only attack *Erica carnea* and its varieties and will not attack other species of ornamental heathers.

Dr. Barnes's investigations on the activities of garden slugs continued in Bedford during the year.

Vol. III of *Gall Midges of Economic Importance*, that concerned with the gall midges of Fruit was published on March 31st, 1948, while Vol. IV that dealing with the gall midges of Ornamental Plants and Shrubs was issued on January 10th, 1949.

Dr. Barnes visited entomological research and advisory centres in Holland during a visit during April 1948 and officially attended the VIIIth Entomological Conference in Stockholm in August. He read a paper on the necessity for biological investigations in the identification of gall midges at this Congress. He also spent an afternoon at the headquarters of the plant pathological service at Lyngby, Denmark, on his way to Stockholm and a day at the south Swedish substation at Lund on his way back. These visits are of material help to his investigations and he was able to make or renew several important contacts with many entomologists.

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Aphis Fabae AND INSECT DRIFT

Dr. Johnson reports as follows:—

Work at Cardington

Identification of the aphids caught during the season of 1947 is now complete, and work is being done on the analysis of the factors affecting their distribution at various altitudes.

In 1948 the procedure adopted at Cardington was changed, and instead of long continuous periods of flying, the day was split up into two-hourly periods in order to see to what extent population changes occur in the atmosphere during the course of a day and night.

It has been found that, broadly speaking, the population of the upper air does not reach any considerable density until towards the middle of the day, and that towards the evening this density diminishes, so that very little aphid activity exists during the night and early morning. This rhythm extends up to all heights we have so far investigated, viz. to 2,000 feet.

The activity of aphids at crop level

The activity of aphids at crop level, which is at the source of supply of aphids to the upper atmosphere, has also been investigated, and it has been found that there is a similar diurnal rhythm during the course of the day, with practically no aphid activity during the hours of darkness. The effect of climatic factors on this diurnal activity and nocturnal inactivity was also investigated during 1948, and is now in process of being worked out statistically.

The effect of wind direction on the pattern of infestation of black aphids on the bean crop

In the spring of 1948 the migration from the winter hosts to the bean crop of *Aphis fabæ* was followed in three ways:—

(a) By watching the rate of departure from the winter host
(b) By watching the rate of infestation of a small pilot bean crop by winged migrants
(c) By means of traps around the main bean crop.

In this way the peak migration periods were determined and wind directions were taken over the same period.

On two subsequent occasions, some weeks after this migration, the pattern of infestation around the edge of the bean crop on Great Field was made. This showed that during the first third of the primacy migration, when the wind was in the north, an excess of aphids was found along the margin exposed to the wind. Later on, when the wind changed to the east, this resulted in a greater density of infestation becoming evident finally along the opposite margin. On the whole however, the wind was mainly from the north east, and it was on the north-east margin that the greatest infestation occurred. Infestation on the south-west margin, away from the wind, was very slight.

The effect of infestation of fabae *on the bean crop*

A small crop of beans was planted in the Lodge garden and alternate bean plants were kept free from Aphis by handpicking. Subsequently the crop was harvested, stem heights measured, weights and numbers of beans determined—with the object of assessing quantitatively the effect of an infestation on the output

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of the crop. This work is still being pursued, but it can be said at the moment that the infested crop produced over 6½ lb. while the uninfested crop produced 14 lb., a difference of approximately 53 per cent. It may be mentioned that the infestation was but moderate and did not destroy any plant.

The development of suction traps

A comparison of the performance of suction traps, sticky traps, and nets has been made, and it has been found that both nets and sticky traps are so greatly influenced by the wind, particularly at speeds under 5 m.p.h., that large errors are likely with these traps.

A special type of suction trap has been devised, which segregates the catch according to 24 periods during the day and the night. It is hoped that by the use of these traps a more accurate picture of populations and activity changes will be possible than has hitherto been the case with the recognised methods of sticky traps and nets.

The fact that suction traps are independent of wind speed over the range of wind speeds 0–6 m.p.h. is very significant, in view of the fact that it is at these wind speeds that most aphid flight takes place.

Translation

The translation of a large key to aphid genera and species by the Russian entomologist, A. Mordvilko, is being made in collaboration with Dr. E. Judenko.

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BEE DEPARTMENT

By C. G. Butler

General

Lectures have again been given by various members of the Department to Scientific Societies, Beekeepers' Associations and other organizations. A discourse on "Bee Behaviour" (125, 126) was given by Dr. C. G. Butler at the Royal Institution, and he also conducted a short course of extra-mural lectures at London University. A book entitled "An Introduction to the Sense Physiology and Behaviour of the Honeybee" has been written by Dr. Butler (127). A Leaflet describing the use of honeybees as pollinating agents in orchards (123) has been prepared for the Ministry of Agriculture and Fisheries, and also a Bulletin on "Bee-Hives" (128). Members of the Department have served on various committees such as the Minister's Bee Disease Advisory Committee, the British Standards Institute Sub-Committee for the standardization of beekeeping equipment, and the British Beekeepers' Association Research Committee.

Bee Behaviour

Considerable advances have been made in the study of the principles underlying the foraging behaviour of the honeybee and a paper describing some of the results of Mr. C. R. Ribband's work on this subject has been accepted for publication (131). Studies designed to determine the usual sequence of foraging duties, if any such sequence exists, and the extent to which these duties are determined by the requirements of the colony and the previous conditioning of the individual, have been commenced by Mr. Ribbands, but have been impeded by the exceptionally adverse weather conditions experienced during 1948. These studies will be continued during 1949. So far the results appear to allow of the tentative conclusion that the effect of foraging distance upon honey yield in Britain has often been seriously underestimated.

In further work carried out by Mr. Ribbands a study is being made of the modification of the behaviour of honeybees that have been subjected to anæsthesia. Bees were captured whilst gathering pollen and nectar from sainfoin or cornflower, and marked after anæsthesia with either chloroform, carbon dioxide, or nitrogen. After chloroform anæsthesia the marked bees returned to the same crops (indicating that their memory was unimpaired) and collected both pollen and nectar as before: after carbon dioxide or nitrogen anæsthesia, however, the bees, although they also returned to the same crops, changed their foraging habits and collected nectar only. Further investigations have shown that carbon dioxide anæsthesia of newly-emerged bees induces them to forage at an early age and eliminates their brood rearing activities. The effects of the carbon dioxide or nitrogen treatment are similar in many respects to an artificial ageing of the bees, but recent work indicates that anæsthesia with these substances does not produce a complete parallel. The theoretical importance of these results lies in the fact that the treatments change bee behaviour from one normal condition to another and, perhaps, indicate the physiological basis of the

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behaviour patterns. A paper embodying these results is being prepared.

Work is also being commenced by Dr. Butler in an endeavour to determine the physiological nature of the behaviour of worker honeybees both in the hive and in the field, and also the development of the nubile and egg laying conditions of the queen honeybee, and of the sexual development of the drones.

Dr. Butler has made an experimental study of the behaviour of worker honeybees when seeking the entrance to their hive, and a paper on this subject which throws further light on the psychology of the bee is being prepared for publication. He has also conducted a series of experiments in an attempt to determine how the male of a solitary bee, *Andrena flavipes*, finds and recognises the female.

Pollen Trapping

The study of pollen collection by honeybee colonies was continued during 1948 by Mr. J. Simpson by means of pollen traps. Previous work has shown that over the whole season colonies in the same apiary sometimes collect very different amounts of pollen from any one source. During 1948 day to day variations of this kind were investigated in the hope of finding some explanation. This aspect of the work is not yet complete and will have to be continued.

Owing to the persistently bad weather, the records of pollen catches during the summer of 1948 were very patchy, little or no pollen being collected for considerable periods. An interesting feature was that during this season, which was notable for the failure of the more important nectar producing plants in the Harpenden district to yield nectar, the collection of pollen from these same sources was very small, and that the bulk of the pollen collected, sometimes in considerable quantity, was obtained by the bees from plants, such as the field poppy (*Papaver rhœas*) which do not produce any nectar.

The Possible Harmful Effect of Various Herbicides and Insecticides on Honeybees

Mr. G. D. Glynne-Jones has, with the co-operation of the Beekeeping Advisory Section of the National Agricultural Advisory Service, made a survey throughout England and Wales in an attempt to determine the extent to which the employment of herbicides and insecticides in the field is proving harmful to honeybees. Beekeepers were asked to report, giving the fullest possible details and submitting samples of the bees, all supposed cases of losses of honeybees by poisoning. Of sixty-three cases of bees reported, thirty were, on the evidence available, considered to have been due to poisoning, the majority of these being directly attributable to the application of arsenical sprays to fruit trees when in flower. Some evidence was also obtained which suggests that the use of D.D.T. in orchard sprays can also be harmful to bees, but no definite conclusions on this point can be drawn from the data available. None of the losses of bees reported could be attributable to the use of herbicides.

The more serious cases of bee poisoning occurred during April and May and were largely confined to the fruit-growing areas of Cambridgeshire and Essex.

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Mr. Glynne-Jones also conducted an experiment on a field scale in order to investigate the possible harmful effects of D.N.O.C. on foraging bees when this substance is used to kill charlock when this plant is in flower. Observations made on colonies of bees in the field itself showed that some foraging bees were killed whilst the spraying was in progress but that no damage was done either to the "house bees" or to their brood. It would appear to be a wise precaution in order to minimise losses of honeybees to recommend that farmers who intend to have charlock sprayed whilst it is in flower should warn neighbouring beekeepers to confine their bees to their hives whilst the spraying operations are actually in progress. The speed with which the sprayed charlock flowers wilt after treatment with D.N.O.C. appears sufficient to deter the bees from returning to them and thus becoming poisoned.

The results of the investigations made by Mr. Way and Miss Synge on the possible harmful effects of D.D.T. and Benzene Hexachloride on bees has now been published (133). It was concluded that although D.D.T. can be shown to be toxic in the laboratory it appears to have no harmful effects in the field even when applied to open blossom. Benzene Hexachloride, on the other hand, proved to be highly toxic to bees when applied to open blossom.

The Reactions of a Colony of Honeybees to its Physical Environment, particularly during the Winter Months

Mr. J. Simpson has confirmed that when a colony of honeybees is subjected to an excessively high temperature the bees collect, and evaporate within the hive, large quantities of water. As the temperature of the air outside the hive falls the temperature within the brood-area is maintained between 32° C.—34° C. by contraction of the cluster of bees resulting in a reduction in surface area, thickening of the insulating shell of the bees and a reduction in the rate of movement of convection currents. Within the temperature range covered by these observations (22° C.—36° C.) the various active movements of the bees forming the cluster such as fanning with the wings and shaking of the body, showed no variation in frequency or intensity sufficient to support the view that extra heat produced by these activities is important in the maintenance of the temperature in the brood-area. The humidity of the atmosphere within the winter cluster formed by a normal colony of bees was investigated over a period of time during which the outside temperature ranged from 0° C.—20° C. When the outside temperature was below 10° C. it was found that the dew-point of the air within the cluster was usually 8° C.—10° C. above that outside the hive, so that the relative humidity of the atmosphere within the brood-area with its temperature of about 33° C. must have been very low. This was confirmed by observation of the absorption or evaporation of water from capillary tubes filled with sulphuric acid of various known concentrations placed within the cluster. Work along these lines is being continued.

Bee Breeding

A start has been made on a programme of work to produce, by means of artificial insemination, sufficient queens of known parentage to head all the Department's experimental colonies. This is

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considered to be most important as it is likely to lead to a considerable reduction in variability between colonies. Comparative trials with a number of different, well-established, strains of bees have been commenced and a strain trial unit has been established in one of the out-apiaries. It is hoped that it will be possible to establish further units not only in the Department's apiaries but also at outside centres in various parts of the country during the next few years. All the queens used in these strain trials are being inseminated instrumentally so that the parentage of their offspring can be guaranteed. Unfortunately bad weather and an outbreak of Nosema disease seriously hampered this work during 1948.

Acarine Disease

Interest has recently been revised in the treatment of Acarine disease by fumigation with the vapour of a burning smoker cartridge impregnated with sulphur. Trials of this treatment have been carried out by Mr. P. S. Milne and members of the N.A.A.S. Bee Advisory Staff on bees of colonies infected with this disease in four apiaries near Harpenden. The colonies used in these trials ranged in size from a small nucleus established from a July cast to full strength colonies. The results that have been obtained are very promising and appear to indicate that this "sulphur" treatment may be a satisfactory and reliable method of treating infected colonies during the active season. Further trials will be carried out during 1949. A short article on the method of preparing the sulphur cartridges and the application of this treatment has been published (129).

Sulphonamide Treatment for American Foul Brood

Further trials of the sulphonamide treatment for A.F.B. were arranged by Mr. Milne during 1948 and the colonies that had been subjected to this treatment in previous years were kept under observation. A recurrence of A.F.B. was confirmed in one of the trial colonies that were treated during 1946, thus providing further evidence that the sulphonamide treatment is not fully reliable and supporting the view expressed in our 1947–48 report that these sulphonamide drugs are unlikely to prove to be of such value in cases of A.F.B. as had been hoped.

European Foul Brood Disease

Miss E. Kops, working jointly with the Bee Department and the Microbiology Department, has been attempting to repeat the observations of Professor R. Burri of the Liebefeld Institute, Berne, on European Foul Brood. According to Burri, E.F.B. is caused by a small bi-pointed coccus, *Bacillus pluton*, which he claims to be a pathogenic dissociant form of *Bacillus eurydice*. He states that *B. eurydice* is a normal symbiont of all adult bees and of all healthy bee larvæ between weaning and pupation. He had grown *eurydice* on ordinary agar and beewort agar and states that after about 24 hours, in most cases, there is an "umwandling" from the short rod *eurydice* to the coccoid *pluton* form. This *pluton* will not multiply on sub-culture, and he has not succeeded in growing *pluton* except as a "dissociation product," as he terms it, of *eurydice*.

Numerous adult bees and larvæ both from healthy colonies and those infected with E.F.B. have been examined culturally and

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microscopically by Miss Kops, but so far no results similar to those of Professor Burri have been observed. Attempts to obtain *eurydice* from healthy larvæ have been unsuccessful, no growth being obtained on ordinary agar plates inoculated with emulsions of such larvæ, but an organism which is apparently *eurydice* has been grown from inocula from healthy adult bees obtained from a number of sources. In no case however, has a culture of this short slender rod changed into *pluton* as seen in smears from diseased larvæ. The large number of *pluton* which can be seen in the microscopic preparations of honeybee larvæ in the early stages of E.F.B. are easily identified, definite in shape and distinctly bipointed. In some cultures the *eurydice* bacilli did appear to shorten to a cocco-bacillus form after a short time, but this form does not appear to be morphologically identical with *B. pluton*. The whole culture did not become coccoid, and no difficulty was experienced with sub-cultures.

Similar results were obtained from attempts to culture *eurydice* and *pluton* from diseased larvæ. This was complicated by the fact that even a small trace of the sporogenic *B. alvei* or *B. orpheus* will spoil a culture since they multiply so rapidly that they swamp a plate in 24 hours. A wide variety of media were used, synthetic media, media prepared from mashed bee larvæ, bee-gut, larval extract, fortified with pollen extracts, yeast and honey. *B. eurydice* was isolated without difficulty from larvæ in the early stages of E.F.B. and appears to be identical with a culture of *eurydice* obtained from Professor Burri. Here too there was sometimes a shortening to a coccoid form still unlike *B. pluton*. No growth of *B. pluton* was observed, except on a soil extract medium. On this medium it did appear the *B. pluton* was growing in its original form without *eurydice* being present at any stage. *B. pluton* could be demonstrated in small colonies of 6–8 organisms at first, and after a few days, some colonies of as many as 60 organisms. It continued in this state of apparent growth for two or three weeks when it disappeared. Two sub-cultures were apparently successful, and a further two doubtful, but by the end of five weeks there was no *pluton* visible on any of the plates. It is hoped to continue this line of work during 1949.

Defective Brood

Mr. Milne noted a widespread incidence of defective brood amongst colonies in the Cotswold area of Gloucestershire during the 1948 season. Infection trials, using material taken from sample combs from these colonies, indicate that the trouble may in some cases be due to a disease with similar characteristics as those that have been described for Sac Brood.

Nosema Disease

Some evidence has been obtained during the last two seasons which indicates that a form of Nosema disease possessing characteristics unlike those previously ascribed to cases of this disease in this country has made its appearance. It appears probable that this form of Nosema which is of a serious nature and often causes premature supersedure, or death, of queen bees and a marked shortening of the life of worker bees, is of American origin. This American

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form of Nosema disease has probably entered this country during the last two or three years either directly with queens imported from the U.S.A., or indirectly via the continent, and is highly infectious. Since this form of Nosema undoubtedly causes serious losses the policy of allowing importation of bees or queens into Britain from the Continent or from Ireland or North America appears to be most unwise. Preliminary trials, carried out by Mr. Hassanein, in attempts to control Nosema by feeding hydrogen peroxide have yielded promising results, and further work along this line will be carried out.

The Feeding of Colonies for Winter

Sugar syrup was fed to two equivalent groups of colonies during late August and early September. Two concentrations of syrup were used—(1) strong, 2 lb. sugar to 1 pint water, (2) weak, 3 lb. sugar to 4 pints water. Each colony was weighed before and after feeding, and the changes in weight were compared with the changes which occurred in a third group of colonies which were not fed at all. 24 lb. of sugar was fed in either strong or weak syrup to each treated colony. Analysis showed that the average net gain in colony weight after feeding with strong syrup was equal to about 95 per cent. of the weight of sugar supplied, whereas after feeding with weak syrup the net gain was only 75 per cent. of the weight of sugar supplied.

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INSECTICIDES AND FUNGICIDES DEPARTMENT

By C. Potter

A number of staff changes occurred during the year, mainly in the form of additions. Dr. Pradhan after taking his London Ph.D. for the work he carried out in the department, returned to India to take charge of insecticide work in that country, and later on in the year Mr. T. D. Mukherjea came over from Dr. Pradhan's laboratory to work with us. Mr. K. A. Lord was awarded his London Ph.D. during the year. Mr. M. E. Elliott has joined the research staff as synthetic organic chemist, and Mr. P. Needham as an Experimental Officer on the Biological side.

The lack of accommodation, and in particular, the lack of facilities for providing controlled environments in which to carry out experiments, continues to be a considerable handicap to the work. A scheme has been put forward for improved accommodation and facilities. There are still some shortages of equipment but considerable progress has been made in remedying deficiencies in this respect.

The work of the department may be conveniently described under five headings. (1) General; (2) Chemical:— (Analytical, Synthetic, Biochemical); (3) Physico-Chemical; (4) Biological; (5) Field work.

General

(a) *Ad hoc* work on organic phosphorus insects. (b) Biological evaluation of samples of Benzene Hexachloride containing different proportions of the isomers. (c) Estimations of the insecticidal activity of residues from the preparation of piperidine by the process of hydrogenation of pyridine.

Organic phosphorus insecticides

Hexaethyl-tetraphosphate (*H.E.T.P.*) At the request of the Agricultural Research Council, the insecticidal activity of samples of H.E.T.P. prepared in three different ways have been compared on adult Flour Beetle (*Tribolium castaneum* Hbst.) using a direct spray technique. No significant differences in biological activity were found between any of the three samples.

The toxicity of H.E.T.P. when formulated in three different media has also been estimated, again using adult flour beetle as the test subject. There were considerable differences in the slopes of the probit lines obtained with the three media, so that it was not possible to make direct comparisons of the toxicity. However, when the differences in the weight of poison deposited, using the three media, were taken into account there did not appear to be any considerable differences in toxicity. The three media were:—(a) Odourless distillate (a highly refined light petroleum oil). (b) 10% v/v odourless distillate emulsified in 0·1% w/v sulphonated lorol in water. (c) 10% v/v acetone in 0·1% w/v sulphonated lorol in water. The stock solutions used were 0·24% w/v H.E.T.P. in odourless distillate, 2·4% w/v H.E.T.P. in odourless distillate and

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2·4% w/v H.E.T.P. in acetone. All the solvents used for preparing the stock solutions were dried over calcium chloride. After keeping the stock solutions of H.E.T.P. for one month they were compared biologically with a further set of freshly made solutions. The month old solutions of 0·24% v/v H.E.T.P. in odourless distillate was non-toxic. The probit line obtained with the old 2·4% w/v H.E.T.P. in acetone solution differed slightly in position, but not in slope, from the freshly made solutions, indicating a slight loss in toxicity. The probit line obtained with the old solution of 2·4% w/v H.E.T.P. in odourless distillate sprayed as an emulsion altered its slope so that it approximated to that obtained with the acetone solution in water, rather than to the slope of the corresponding emulsion for the freshly prepared 2·4% w/v H.E.T.P. in oil solution. The main conclusion that may be drawn from these experiments seems to be that, although some decomposition had occurred in the stock solutions, it had been insufficient to reduce the toxicity of the spray solutions, where strong stock solutions were used, although it had caused a change in the slope of the probit lines.

The insecticidal activity of H.E.T.P. has been compared with that of nicotine as a contact insecticide, by means of a direct spraying technique. Both insecticides were formulated in aqueous medium containing 10% v/v acetone, and 0·1% w/v sulphonated lorol. The insects used as test subjects were adult apterous, viviparous parthenogenetic females of pea aphid (*Acyrthosiphon pisum*, Harris) adult mustard beetle (*Phaedon cochleariae* F.) and the larvæ of the diamond back moth (*Plutella maculipennis* Curt.). H.E.T.P. was about 10 times more toxic than nicotine to all these insects under the conditions of test.

O.O-Diethyl O.p-nitrophenyl thiophosphate (*E*605). The toxicity of this material was compared with that of H.E.T.P. under the same conditions of test as those outlined above for the comparison of H.E.T.P. and Nicotine. The test subjects used were adult flour beetles (*Tribolium castaneum* Hbst.) and the larvæ of diamond back moth (*Plutella maculipennis* Curt.). The E605 proved to be of the order of 10 times as toxic as the H.E.T.P. to these insects.

Benzene hexachloride

At the request of the Agricultural Research Council two samples of the gamma isomer of benzene hexachloride obtained from different sources were compared biologically for their insecticidal activity, using a direct spraying technique and the adult grain weevil (*Calandra granaria* L.) as test subjects. No significant difference was found between the biological activity of the two samples.

A sample of so-called enriched material, which consisted of the gamma and delta isomers and perhaps other material, was tested at the same time as the two samples mentioned above and was about $\frac{1}{3}$ as active as the pure gamma isomer. Since the delta isomer comprised approximately $\frac{2}{3}$ of the so-called enriched material this indicated that the delta isomer had in this instance no insecticidal activity and no synergistic effect.

At the request of the Agricultural Research Council and the Chemical Research Laboratory, Teddington, some tests were carried out to determine the insecticidal activity of a series of fractions of a residue formed in the process of preparation of piperidine by the

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vapour phase hydrogenation of pyridine. The crude residue had already been reported to have insecticidal activity.

Ten fractions were sent to us to test. The overall boiling range of these fractions was from below 80° C. to 180° C. at 7 mm. pressure. They were tested in aqueous medium containing 10% v/v acetone and 0·1% Lissapol N (an oil soluble emulsifier consisting of condensed polyethylenes), at 0·1%, 0·5% and 1·0% v/v. The test insects used were adult apterous, viviparous, parthogenetic females of bean aphis (*Aphis Fabae* Scop.), adult saw toothed grain beetle (*Oryzaephilus surinamensis*) eggs and 5th instar larvæ of tomato moth (*Diataraxia oleracea*) and 5th instar larvæ of cabbage moth (*Mamestra brassicae*). Very little toxicity was shown by any of the fractions. The higher boiling fractions at the 1% dilution gave a high percentage kill of aphids, but at this dilution and at the two lower dilutions no appreciable mortality occurred with the other test subjects.

Chemical

Analytical

Pyrethrum. During the past year a series of estimations of the pyrethrin contents of samples of pyrethrum flowers have been carried out in connection with a world-wide collaborative scheme. Two samples were examined using three methods, viz., the Wilcoxon, the Seil and the Ripert techniques. Since the results of all the collaborators have not yet been received and examined, it is not possible as yet to reach any conclusions. The purpose of the work is to find a method for routine analyses where producible results may be obtained, irrespective of the operator and location. Additional sets of tests to compare the analytical results obtained with samples stored in the refrigerator with those that had travelled round the world were also carried out. This was done to determine if deterioration or any other effects occurred during travel which might affect the results obtained by workers in different parts of the world.

Rotenone. At the request of the National Agricultural Advisory Service (Wye), a series of rotenone analyses were carried out on a group of Derris and Lonchocarpus dusts.

Synthetic

This work has only been in progress for a few months. The present aim in the first instance, is to study the relationship between insecticidal activity and chemical structure with especial reference to the pyrethrins. For this purpose synthetic routes to keto-alcohols related to pyrethrolone and cinerolone are being explored and it is intended to esterify any such compounds obtained with trans-chrysanthemum mono-carboxylic acid (isolated from a concentrate of the natural pyrethrins) and examine the biological effect of these esters.

Biochemical

Work on the effect of insecticides on the respiration of insects has been continued. An electro-magnetic device has been elaborated for distributing dusts inside a modified Barcroft apparatus without disturbing the thermal equilibrium of the apparatus. It is now

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possible to observe the effects, if any, of poisons, on the oxygen uptake of insects during the first few minutes after treatment.

A survey of the effects of a variety of insecticides of widely different chemical types is at present being carried out and a number of substances of known physiological importance are being included.

Data has already been obtained on the action of several chemicals on the oxygen uptake of adult *Tribolium castaneum* Hbst. but as yet the results have not been examined in detail. It is not thought wise to report any data from this section of the workuntil it has been carried further, since great care has to be used in the interpretation of the results.

PHYSICO-CHEMICAL

The effect of particle size on toxicity

Work on the effect of crystal size on the toxicity as direct contact insecticides of suspensions of pure 2,2 bis (parachlorophenyl) 1,1,1, trichloroethane (D.D.T.) and rotenone has been continued.

It has been shown that the results previously obtained with D.D.T. on adult *Tribolium castaneum* Hbst. (which is not normally susceptible to rotenone) also applies to adult *Oryzæphilus surinamensis*. These results show that toxicity increases as the crystal size increases within the limits tested. It has now been found that when rotenone is used on adult *O. surinamensis* exactly the opposite effect occurs, that is, the toxicity increases as the crystal size decreases.

With both poisons it appears that a larger amount of poison is retained on the surface of the body with the larger crystal sizes,and this may be a partial explanation of the results obtained with D.D.T. but obviously cannot explain the results obtained with rotenone. Some reason for the effects obtained and the cause of the differences in behaviour between rotenone and D.D.T. are now being sought.

Assuming that rate of penetration of the cuticle is a limiting factor and that this, in its turn, is governed by the lipoid solubility of the rotenone, the results obtained with this poison may be explained by the enhanced solubility of small crystals.

Working on the same hypothesis with D.D.T. it would appear that overall lipoid solubility of the crystals was not the limiting factor, and that the increase in the amount retained was therefore more important. This heavier dosage might be increasing the amount of poison penetrating the cuticle over the whole area of the body, or it might be having its effect at some specially sensitive point. It was thought that the legs, particularly the tarsi, might be sensitive areas and since in addition the large needle shaped crystals of D.D.T. are retained somewhat preferentially in this area, some experiments were made with insects and their legs removed, but these gave negative results.

It is now being inferred that the cuticle as a whole is more easily penetrated by D.D.T. than rotenone, and an approach to the problem is being made by taking into account the structure and properties of the epicuticle and by studying the effect of various treatments of the epicuticle on the toxicity of the two poisons.

Surface-active agents

A study of the effect of surface active agents on the toxicity of contact insecticides, applied directly to the body of the insect, was started by Dr. Potter in the U.S.A. in the latter part of 1946

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and carried on in that country to the end of the year. This work has been continued at Rothamsted, and a large quantity of data has been obtained. The object of this study was to determine the magnitude of the difference, if any, of the toxicity of contact poisons produce by different surface active agents, and to find, if possible, a general principle on which the differences could be based. The data obtained are not yet complete, and have not been fully analysed and examined.

Biological

Natural variation in resistance

During the course of the year, work was resumed on the variation that occurs naturally over a long period in insect populations.

The effect of differences in host plant on the resistance of a given insect species

The pea aphid *Acyrthosiphum pisum* was reared on two different host plants, beans and clover, side by side in a glass house. The strain from the bean was used to colonize the clover.

Samples of populations from both host plants taken on the same day were tested for their resistance to rotenone.

Four experiments were carried out, but only one gave satisfactory results. This experiment gave non-heterogeneous data and an L.D.50 of 0·00015% w/v of rotenone for the insects taken from beans, as compared with 0·00021% w/v for the population on clover. A previous experiment (23.8.43) had given an L.D.50 of 0·00015 for the population on beans as compared with 0·00037 for that on clover. These figures indicate that the insects feeding on clover are more resistant than those feeding on beans, at least where rotenone is the poison. The other experiments were not satisfactory, owing either to considerable heterogeneity of the data or disease in the populations which only showed up after treatment. Owing to difficulty with disease and synchronization of the development of suitable populations it is difficult to obtain satisfactory data on this point, but the work is being continued.

Cuticle structure

M. J. Way is concluding studies started at Cambridge on the structure and physiology of the larval cuticle of *Diataraxia oleracea* —the tomato moth.

Soon after work was begun it became clear that the fine structure of the cuticle would have to be studied in detail before it would be possible to commence work on the penetration of insecticides.

The formation of the new cuticle has been studied in order to determine the presence and position of various layers which are difficult to define in the mature cuticle. In addition the electron microscope has been used to study fine structure.

Fundamentally the cuticle of this insect is typical of insects in general, and consists of a well defined epicuticle and endocuticle. Particular study has been made of the former, which probably acts as the main barrier to the penetration of materials through the cuticle. The formation of the cement layer, the formation and regeneration of the wax layer, and the "chemistry" of the lipo-protein layers of the epicuticle have been studied.

The pore canals have been suggested as a convenient system along which insecticides may penetrate into the body of the insect.

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Their structure and functions in the *Diataraxia* cuticle have been studied in detail. Of interest is the fact that they are functional as conducting canals only in the early stages of development of the cuticle. Afterwards their contents become chitinized and sclerotized and they appear to develop a skeletal function.

The electron microscope has been used to determine the relationship of the pore canals to both the epicuticle and the outer cuticle. Laminæ of the latter observed in surface view in the electron microscope showed a clear picture of pore canals and the surrounding chitin structure. No information was obtained on the relationship between chitin and protein in the endocuticle. In the 60 μ thick inner endocuticle of the mature insect pore canals are absent, but the porous structure of this layer as shown by sections examined in the electron microscope suggests that even in the absence of pore canals it need not act as a barrier to the passage of materials.

Insect rearing

The search for suitable species of insects that feed on the growing plant and are suitable subjects for the study of insecticides, continues to be an important part of the work of the department.

Studies of the effect of temperature and light of the biology of several species have been made, and it has been found that additional light will break the diapause in some species. So far as we are aware this is the first time this effect has been recorded.

The following species of insects have been worked on during the current year:—

Insects feeding on growing plants, Hymenoptera:—*Athalia colibri*. F. (Turnip sawfly). Lepidoptera:—*Diataraxia oleracea* L. (Tomato moth); *Plutella maculipennis* Curt. (Diamond back moth); *Mamestra brassicae* L. (Cabbage moth); *Lymantria dispar* L. (Gypsy moth); *Pieris brassicae* L. (large cabbage white butterfly); *Plusia gamma* L. (Silvery moth); *Phragmatobia fuliginosa* L. (Ruby tiger); *Sphinx ligustri* L. (Privet hawk moth); Coleoptera:—*Phaedon cochleariae* F. (Mustard beetle); Rhynchota Aphididæ:—*Macrosiphoniella sanborni* Gill. (Chrysanthemum aphis); *Macrosiphum euphorbiae* Thos. (Potato aphid); *Acyrthosiphon pisum* Harris. (*Macrosiphum pisi*) (Pea aphid); *Aphis fabae* Scop. (Bean aphid); *Myzus circumflexus* Buct. (Mottled arum aphid); *Myzus persicae* Sulz. (Peach-potato aphid).

Insects feeding on stored products. Lepidoptera:—*Ephestia kuehniella* Zell. (Mediterranean flour moth); *Sitotroga cerealella* Ol. (Angoumis grain moth); *Galleria melonella* L. (Large was moth); Coleoptera:—*Tribolium castaneum* Hbst. (Flour beetle); *Tribolium confusum* Duv. (confused flour beetle); *Oryzaephilus mercator* L. (Merchant grain beetle); *Calandra granaria* L. (grain weevil); *Tenebrio molitor* L. (meal worm). Orthoptera:—*Periplaneta americana* L. (American cockroach).

Studies of the effect of herbicides and repellents on bees

The work commenced in 1947, in collaboration with the bee department, on the effect of the newly developed herbicides on bees, was continued during this year, and most of the time was spent on the development of techniques for the study of the toxic and repellent properties of various chemicals to the Honey Bee.

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An investigation of the toxicity of films of the acid 3:5 Dinitro-o-cresol (DNOC) and its sodium salt, which are both used as herbicides, showed that a film of the acid was a rapidly acting poison under a wide range of conditions, whilst a film of the sodium salt was hardly effective unless the humidity of the atmosphere over the films was such that actual condensation of the moisture took place at the treated surface. When this occurred the bees were as quickly affected as with the film of the acid.

Using films of the acid 3:5 DNOC deposited on a leaf surface (cabbage), it was found that such a film rapidly became more effective as judged by rate of 'knock-down' when the deposit was increased from 0·010 mg./sq. cm. to 0·40 mg./sq. cm., and it was calculated that under field conditions when the DNOC was used as a herbicide, the maximum deposit was unlikely to be 0.066 mg./sq. cm. From this it is assumed that continued foraging on the treated flowers by bees was likely to prove fatal.

A technique was developed for the evaluation of various repellent materials to the Honey Bee. The experiments were conducted in a greenhouse, which contained a small colony and allowed normal flight. This arrangement made it possible for reproducible results to be obtained under semi-controlled conditions, and experiments conducted in the field indicated that differences in repellent properties recorded in the greenhouse, were applicable under normal and foraging conditions.

Of the various chemicals tested, which included the recently developed mosquito repellents, a proprietary wetting agent which consisted of a solution of sodium salts of sulphonated secondary alcohols showed the most promise as a repellent.

FIELD EXPERIMENTS

The two experiments on the control of wireworms in Little Hoosfield, started in the autumn of 1947 using wheat as a test crop, have been carried on, and the crop yields for the various treatments have been obtained. In experiment 1, on the effect of different chemicals Ethylene dibromide at 45·4 lb. per acre gave the best results—giving a yield of 32·1 cwt. per acre compared with 8·9 cwt. per acre for the controls. A Gammexane dust (3·5% crude benzene hexachloride containing 12–14% gamma isomer) broadcast at 2 cwt. per acre gave a yield of 30·6 cwt. per acre; D.D. (said to be a mixture of about equal parts of 1, 3 dichloropropene and 1, 2 dichloropropane with small quantities of other chlorinated compounds) 28·3 cwt. per acre; gammexane combine drilled with the seed at the rate of $\frac{3}{4}$ cwt. per acre gave a yield of 24·8 cwt. per acre. Seed dressed with an experimental mixture prepared by Imperial Chemical Industries containing organic mercurials equivalent to 1% mercury and 20% technical gamma isomer, at the rate of 2 oz. per bushel of seed gave a yield of 24·0 cwt. per acre. A dust containing 5% D.D.T. combine drilled with the seed at 1·2 cwt. per acre gave a yield of 20·7 cwt. per acre.

The second experiment comparing the effects of treatment with benzene hexachloride in the form of gammexane, applied in different ways, confirmed the good results obtained with the seed dressing and indicated that combine drilling at the rate of 1 cwt. per acre, gammexane had slight deleterious effects while dressing below $\frac{1}{4}$ cwt. per acre might well prove satisfactory.

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FIELD EXPERIMENTS

By the PLOT COMMITTEE

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Rothamsted Field Experiments, 1948

The season 1948, though dull in the summer months, was not unfavourable to crop growth. Work on the plots proceeded without serious hindrance: cereal and root yields were up to standard while potatoes were excellent.

The drought of 1947 continued till the end of November, consequently the autumn sown wheat and beans were drilled in very dry seedbeds. The beans that were drilled were completely lost through birds, but the ploughed-in beans and the wheat made good plants and came through the very mild winter without appreciable loss. After a rather wet January the spring was dry, mild, and bright and generally favourable. There was plenty of moisture in May and June, but July with less than an inch of rain was unusually dry. In a summer when the press was full of complaints about ruined harvests, the August rainfall at Rothamsted at 2·6″ was practically the average while September was drier than usual. There were, however, a rather large number of wet days during the harvest period, but none the less crops were secured in good condition. October and November were also drier than usual but the weather broke for the lifting of late sugar beet and mangolds. The whole year with 27·2 inches of rain was 1·3 below average.

The number of plots handled by the experimental staff is shown in the following table:—

	Corn and Linseed	Potatoes and Roots	Hay	Grazing	Total
Classical	101	39	47	—	187
Long Period Rotations	215	232	56	3	506
Annual Experiments	501	287	—	—	788
Total	817	558	103	3	1481

Unfortunately 64 plots of beans and two plots of turnips on Agdell were lost through birds and disease respectively so the number of plots harvested was 1,415.

CLASSICAL FIELDS

Broadbalk (Continuous wheat, 105th year)

The wheat was drilled in a very dry seedbed on October 24th. There was a good germination and the plant wintered well. Section II, after bare fallow, was shorter in the straw and weaker than usual. There was little lodging except on the heavier plots of Section I near the Wilderness. The field was hand pulled for wild oats between mid June and the end of July and very few of the panicles

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reappeared before harvest. Bird damage was probably less severe than usual. The crop was cut on August 19th and carted a week afterwards in very good order: it was one of the brightest pieces of wheat carted in a year when much of the corn was blackened.

Wheat and fallow (93rd year)

This was drilled at the same time as Broadbalk. On the whole the crops were better than usual, and better than the continuously unmanured plot on Broadbalk, and appeared to show a slight benefit from the three years' fallow as compared with the one year fallow.

Hoosfield (Continuous barley, 97th year)

The barley was sown on 31st March and early growth was good. Wild oats were pulled during the summer on all plots except 50, 5A, and 3C which were cut green with the exception of a small area that was hand pulled and left to ripen. Before harvest a second lot of oat panicles much less numerous than the first had appeared on all plots. The dung plot was badly laid this year and very weedy on the west end. Elsewhere the field was fairly clean apart from the oats. The promise of the yield was quite up to average.

Barnfield (Continuous mangolds, 73rd year)

The first sowing of mangolds and sugar beet made under good conditions on April 28th was completely ruined by flea beetle in spite of all attempts to save the plant. On June 9th the field was redrilled with mangolds only, and the second sowing grew fast and continued to make growth well into the mild autumn. Lifting commenced in early November and later the conditions became very wet and sticky. In view of the late sowing the crop was better than might have been expected.

Park Grass (Continuous meadow hay, 93rd year)

It was a good year for hay. There was a taller growth of grass than usual on most plots, but legumes were not so conspicuous. The first cut was taken on 16th June; the second crop came away quickly and was cut on the 9th of October to give a much better yield than average.

Agdell Field (Four course rotation. Swedes, barley, clover or fallow, wheat, 101st year, 1st crop of 26th course)

The field was due to carry swedes in 1948, but for many years negligible yields of roots have been obtained on account of finger and toe disease. Only plots 1 and 2, where the disease is most serious, were sown in order to maintain an area of infection in view of the possibility of carrying out field experiments on controlling this disease. There was a splendid plant up to the time of singling, but as usual the roots on plots 1 and 2 were practically entirely destroyed later in the season and no yields were taken.

Long Period Rotation Experiments

Four course rotation (potatoes, barley, ryegrass, wheat 19th year)

The experiment measures the first year and residual effects of dung, straw compost, raw straw plus artificials, and two phosphatic fertilizers. A summary of the results of 14 years of this Rotation will be found in the Report for 1946, p. 82. The potato crop of

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1948 was particularly promising and showed the effect of the extra nitrogen applied to half plots. Barley was about average, the plots receiving straw and extra nitrogen looked very well in the spring but as usual was completely lodged before harvest, nevertheless the direct application gave a yield of 36·5 cwt. grain per acre. Autumn sown wheat failed twice through rough seedbed and bird damage and was finally replaced by Atle spring wheat drilled on March 8th. This germinated well but never made good growth and the wheat came to harvest short, thin, with very poor ears. The ryegrass was poorer than usual particularly on the rock phosphate plots where bare patches were noticeable.

Six course (sugar beet, barley, clover, wheat, potatoes, rye, 19th year)

The experiment measures the responses to each of the three common nutrients yearly. Most of the crops in this rotation were above average in 1948. Potatoes at 9·5 tons were good and responded well to nitrogen and potash, sugar beet 11·5 tons was much above average and an even plant, but apart from the usual increase for nitrogen in the tops, fertilizer responses were small. Rye was tall and even, some of the plots being over 6 feet in height; barley clean, standing and uniform, a very fine crop averaging 36 cwt. per acre. The red clover cropped well with a full plant but haymaking conditions were unsettled and the crop was secured with great difficulty. Potash was the most effective manure for this crop. Wheat was the worst crop; the first sowing failed and a late autumn sowing on November 12th gave an irregular crop which lost further plant in spring, the yield, however, was better than appearances suggested and averaged 26·6 cwt., slightly more than the rye which looked much more impressive in the field. All cereals gave good responses to nitrogen. This rotation is summarized over the 19-year period 1930-48 on (p. 90).

Three course (potatoes, barley, sugar beet, 16th year)

The experiment measures the direct and residual effect of straw compost, raw straw plus artificials, and fertilizers only without organic matter. All the crops in this rotation did well. The barley as usual was a good even clean crop yielding on the average 33·5 cwt. grain. Potatoes at 10·4 tons per acre were well above the average and made such rapid spring growth that they had to be earthed up much earlier in the season than usual. Straw gave quite marked direct and residual effects on potatoes. A strip on the east side of the sugar beet was damaged on May 14th by the drift of weed killer from a neighbouring crop, but was redrilled at once with soaked seed and in the good growing weather which followed the new plants caught up with the rest. The final crop at 34·6 cwt. of sugar was slightly below average.

Two course rotation (7th year)

A long period experiment testing the cumulative effects of various levels of agricultural salt applied to sugar beet, with half rates on the following barley crop. Both sugar beet and barley in this rotation were good crops. One strip of plots of the sugar beet were damaged by weed spraying but immediately repaired (see note on adjoining sugar beet three course rotation). Salt gave an increase

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of up to 10 cwt. of sugar per acre, whether applied in winter or in the seedbed. Muriate of potash had little effect on either beet or barley.

Deep cultivation rotation—six course (5th year)

A rotation of sugar beet, barley, seeds, wheat, potatoes, oats testing 7″ v. 14″ ploughing (for beet, wheat, potatoes only); 0 v. dung; 0 v. superphosphate; 0 v. muriate of potash (for beet and potatoes only). The deep ploughing for sugar beet exposed much subsoil and the plant on these plots was slightly thinner and more irregular than elsewhere. A serious attack of flea beetle was successfully controlled by three dustings. Later in the season the crop made wonderful growth. Heavy yields of 16 tons per acre were recorded, and the final result of the deep ploughing was a loss of 1·1 tons roots per acre. Barley gave the excellent crop of 41 cwt. grain per acre which tended to lodge on the plots previously dunged for sugar beet. On the land deep ploughed in 1947 the barley looked a little better and had a brighter colour than on the shallow ploughed areas, but this was not reflected in the final yield. A good crop of seeds was secured with grasses tall and predominating over the clovers. The wheat on this rotation was the best on the farm with a yield of 41 cwt. There was a slightly thinner plant on the deep ploughed plots which showed much subsoil. These plots looked poorer throughout autumn and winter but they filled out well and all looked excellent at harvest time; they yielded 3·4 cwt. less than the shallow ploughed plots. The potato section was ploughed to full depth (13″) for the first time in 1948. In 1943 the full depth could not be reached and in 1946–47 the ground was too wet to plough deep for wheat. In spite of this the subsoil that came up in 1948 showed less red clay than elsewhere and crumbled easily in the winter. Potatoes made a fine crop of 15 tons per acre and showed big response to dung and potash. Oats started with a rather thin plant in spring but filled out to an excellent crop, tall and heavy headed, in July the oats on plots that had been deep ploughed for potatoes had a better colour than the rest, and the land was somewhat less weedy. There were no marked treatment effects in the final yields. A few plots showed excessive amounts of raw subsoil which on these particular areas appeared to depress the yield.

High Field grazing experiment

This experiment, carried out for the Royal Agricultural Society of England, measures the residual effect of cake fed on pasture as compared with the conventional manurial equivalent applied as fertilizer, the control plots having neither cake nor fertilizer. It was begun in 1937 and was in full cycle by 1940. In 1948 plots 4, 5 and 6 were grazed with cattle and sheep to measure the second year effect of cake or fertilizers applied in 1946. By this time every block of the experiment had completed three cycles and the experiment was terminated.

The Annual Experiments

Potatoes

The annual potato experiments were put down in Sawyers II which had previously carried four corn crops. The experiments were repetitions of those carried out in previous years with only slight

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modifications. The season was excellent for potatoes and all plots grew well and were clean and full of growth right up to lifting time.

Experiments with dungs and organic manures. Ten different types of farmyard manure were tested at single and double rates in this experiment which also included rotted bracken. Rates of application of dung ranged from 2·6 to 8·7 tons per acre in the single dose according to the amount of litter and period of storage. All dung at the single dose gave increases ranging from 1·5 to 3·0 tons per acre; the lightest dressing, 2·6 tons, of an overyear dung from bullock boxes gave an increase of 2·6 tons of potatoes. There was marked falling off at the double rates, the increases ranging from 2·1 to 3·1 tons. In the absence of organics there was no response to nitrogen but a large response to potash of 3.8 tons. In presence or organics the response to nitrogen was good, particularly at the lower level of organic manuring. All dungs and also bracken greatly reduced the potash responses.

Time of planting experiment. This experiment now in its 4th season was designed to test the spread of virus diseases in the potato crop and is more fully discussed by the Plant Pathology Department. The earliest planting, April 10th, gave 12·2 tons of potatoes, the latest, May 22nd, gave 6·9 tons. Potash was by far the most effective nutrient.

Cultivation experiment. This was a continuation of an experiment testing the effect of earthing up and of shallow v. deep inter-row cultivation of potatoes. A further treatment was a straw mulch applied along the rows after the first deep cultivation. There was also a test of fertilizers on the flat v. fertilizers in the ridges. The crop was a very good one, and grew so fast in the early summer that it had to be earthed up a fortnight earlier than usual and consequently only one deep inter row cultivation was possible. Neither earthing up nor the inter-row cultivations had any effect on the crop, but the straw mulch increased the yield by 1·8 tons per acre. Fertilizer in the ridges produced 1·1 tons more potatoes than the same quantity of fertilizers broadcast on the flat before ridging. Both earthing up and mulching reduced the proportion of greened tubers.

Linseed experiments

Two experiments were put down on Bones Close.

(1) Testing times of sowing, seed rates, and each of the three common nutrients.

(2) Testing two rates of a complete fertilizer broadcast, and half rates drilled.

The plant came away well but was attacked by flea beetle. The effects of this was very much more serious on the late sown plots which practically failed. There was some indication in the field that the heavier dose of fertilizer drilled with the seed had injured the plant. Both experiments were marred by a very bad infestation of 'goose grass' which in certain cases completely obscured the crop. The weed was worst on plots generously manured. Threshing was exceedingly difficult and there was much weed seed with the grain. The best plots, yielding 11 cwt. per acre, were early sown and without fertilizer. Late sowing owing to flea beetle damage only gave 2

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cwt. per acre. Fertilizers either individually or in mixture had very little effect, and the application of 4½ cwt. with the seed was slightly detrimental.

Wheat

Six experiments were set down on this crop.

(1) Eyespot experiment, Little Knott, a continuation of work carried out by the Plant Pathology Department and reported by them.

(2) Wireworm experiment, Little Hoos, two experiments testing modern fumigants and their method of application against wireworms. These are reported by the Insecticides Department.

(3) Inoculation experiment, Long Hoos. The purpose of this experiment was to test on spring wheat bacterial inoculum containing heteroauxins for which good results had been claimed in France. A fair crop of 22 cwt. of wheat was grown which showed a good response to nitrogen applied as sulphate of ammonia but no effect of the inoculum.

(4) Residuals in autumn wheat of organic manures applied to potatoes in 1947, Great Harpenden. The measurement of dung residuals in cereal crops has been carried out for many years. A heavy crop of 41·9 cwt. of wheat was grown which showed visible residual effects due to the organics in the early stages. These effects were less marked at harvest time but still noticeable. Raw straw plus artificials, which was one of the worst treatments in the potato crop of 1947, gave the most conspicuous residual effect in wheat amounting to 7·2 cwt. for the double dose of straw.

(5) A small experiment was put down to compare 5 varieties of spring wheat and three varieties of autumn wheat sown in the spring. Three nitrogen levels were also tested. Of the varieties used Fylgia and April Bearded were the earliest, but the autumn wheats were very late to harvest and the last of these was not cut till September 12th.

Spring sown cereals

Long Hoos, second year. This was a repetition of the experiment of 1947 on exactly the same lines. The seed was sown on March 17th. The mean yields without nitrogen for the various crops were oats (S.84) 14·6 cwt., spring wheat (Atle) 18·2 cwt., autumn wheat (Bersee) 13·4 cwt., barley (Plumage Archer) 22·5 cwt. All crops responded well to nitrogen up to a level of 3 cwt. of sulphate of ammonia per acre; but the further responses to 4½ cwt. of sulphate of ammonia were negligible. At all nitrogen levels barley was the most productive crop, though at 3 cwt. of sulphate of ammonia and still more at 4½ cwt. lodging occurred. Phosphate responses were insignificant, but barley and Bersee wheat responded to potash.

Beans

Great Field I. Two bean experiments were put down in this field, but one testing the combine drilling of fertilizer was completely destroyed by birds. An experiment testing variety and cultivation factors had all the seed ploughed in, and on the whole gave a very good plant. Two early sown blocks drilled on October 28th, looked better during winter and early spring than the remaining two that were sown on November 18th. Four different strains of seed all yielded much the same, the average yield being 24·5 cwt. grain per

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acre, a very satisfactory crop. As usual a high seed rate, 3 cwt. per acre, was distinctly more satisfactory than a lower rate, 2 cwt. per acre. The extra cwt. of seed gave a further 3½ cwt. grain. The yield of straw was nearly 2 tons per acre for the crop grew very tall.

Fertilizer placement experiments

Two of these were carried out on Long Hoos using the special drill made by the National Institute of Agricultural Engineering, one on sugar beet and the other on peas for threshing. These experiments are part of a series carried out for the most part at outside centres; they are reported by the Chemistry Department.

Woburn Field Experiments, 1948

Classical Experiments

The permanent wheat and barley land was once again fallowed in 1948 making two years' fallow since the last crops were taken.

Long Period Rotation Experiments

Six-course rotation, 19th year

This experiment is on exactly the same lines as the one at Rothamsted except that in recent years the variety of wheat grown has been Square Heads Master instead of Yeoman. Crops were on the whole satisfactory in 1948. Sugar beet gave an average yield of 9·5 tons which is very close to the mean of all years. Potatoes at 8·9 tons were slightly better than usual. Barley produced the excellent crop of 27·5 cwt. per acre, whereas wheat yielded 20·8 cwt. and rye 21·0 cwt. All crops except the clover which this year was trifolium owing to a failure of the main sowing, responded well to nitrogen, but phosphate and potash were ineffective.

The first sowing of wheat failed through bird damage and the crop was resown on November 14th, a fair crop resulted but there was much shrivelled grain. Rye sown on November 15th did not suffer from bird damage. The results of this experiment over the 19-year period 1930-48 are summarized on p. 90.

New green manuring experiment, 11th year

This experiment compares undersown clover, undersown ryegrass, lupins and rape as green manures for autumn cabbages followed by barley. In 1948 a fair crop of barley, 22·4 cwt., was grown which showed a striking response of 8 cwt. of grain for 2 cwt. of sulphate of ammonia. Of the green manures turned in for the previous cabbages, clover was the best and ryegrass the worst in its effects on the barley.

Ley arable rotation, 11th year

This experiment tests the value of three years' ley and three years' lucerne as a means of building up soil fertility in comparison with rotations without leys (for full description see Rothamsted report, 1938, p. 135). Block 3 now begins its third rotation. Potatoes showed a pronounced residual effect of 2·23 tons due to 15 tons of dung applied two years previously. The level of cropping was excellent, mean yield 16 tons. The ley plots were sown at the end of March and gave no less than 7 grazings. The grass cuttings from these plots expressed as hay yielded 4·3 tons per acre. This

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was by far the most productive first year grazing season on record. Lucerne sown on May 18th showed some loss of plant during the season especially on plots which had frequently grown lucerne in past years. Block 5 shows the second years' test crop, barley, which at 30·6 cwt. was the best crop so far grown in this experiment. It showed small but appreciable residues of dung applied to the previous potato crop, but very little effect due to the previous systems of cropping. Blocks 1 and 2 showed leys in their 2nd and 3rd years and various arable crops. In 1948 the 2nd year of the ley at 4·4 tons of hay equivalent was more productive than the third year at 3·4 tons. Third year lucerne gave 3·2 tons of hay during the season, and 2nd year lucerne 4·3 tons. Wheat failed twice from autumn sowings due to birds and was resown in the spring. The final yield was only 14 cwt. 1 year seeds for hay undersown in wheat in 1947 failed in the summer drought and were resown on the bare ground in the spring of 1948. Only a poor crop of 1·2 tons per acre resulted. Sugar beet was a satisfactory crop of 10·8 tons with a rather high proportion of tops. This experiment is summarized on p. 94.

Organic manure experiment, market garden crops, 7th year

This experiment tests the effect of yearly applications of dung, vegetable compost, sewage sludge, and sewage sludge compost on a rotation of vegetable crops. The organics are applied at 15 and 30 tons per acre to peas and to red beet. Sulphate of ammonia at several levels is also tested. The peas drilled on March 16th turned out a very weedy crop and there was a rather large proportion of unfilled pods. Better germination was noticed on the plots receiving organic manures, but the crop was very variable. Dung increased the yield of saleable peas and sludge decreased it. There was no advantage from the addition of sulphate of ammonia. Red beet was a gappy plant partly owing to an attack of flea beetle; there were more plants where organics were applied. There were many bolters and the number of these was increased by those treatments which increased the crop yield. The yield of bulbs was very small on the control plots but was considerably increased by organics, especially dung and sewage sludge. Sulphate of ammonia was also effective.

Annual Experiments

The only annual experiments at Woburn in 1948 were replications of the two linseed experiments as carried out at Rothamsted.

Six Course Rotation Experiments, 1930-1948

In 1930 two long-period rotation experiments were started, one at Rothamsted and the other at Woburn. The purpose was to provide data on the effects of varying amounts of the three standard nutrients, nitrogen, phosphate and potash on the yield of the six crops of the rotation in the different weather conditions of successive years.

The rotation is sugar beet, barley, clover, wheat, potatoes, rye. For the first 4 years the rye was harvested as green fodder, but subsequently it has been carried on to maturity and weighed as

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grain and straw. The crops rotate on six areas on each farm so that each crop of the rotation is present every year. Within each area there are 15 plots consisting of three sets of 5 treatments, testing 5 levels of nitrogen, 5 levels of phosphate, and 5 levels of potash respectively. The plots do not receive the same treatment throughout, but on each plot the 15 treatments follow each other in a definite order in successive years, thus avoiding cumulative effects of any nutrient. In each set the order is 4, 3, 2, 1, 0. The 15 treatments are :

Nitrogen set 0, 1, 2, 3, 4 units of N with 2 units of P and 2 units of K
Phosphate set 0, 1, 2, 3, 4 units of P with 2 units of N and 2 units of K
Potash set 0, 1, 2, 3, 4 units of K with 2 units of N and 2 units of P

The fertilisers are sulphate of ammonia, superphosphate, and muriate of potash. The units are 0·15 cwt. N per acre, 0·15 cwt. P_2O_5 per acre, and 0·25 cwt. K_2O per acre. Thus in terms of fertiliser the nitrogen dressings ranged, in round figures, from 0 to 3 cwt. sulphate of ammonia, the phosphate from 0 to 3½ cwt. superphosphate, and the potash from 0 to 2 cwt. muriate of potash. No dung is given, but a uniform application of calcium carbonate is applied after sugar beet and again after potatoes. The experiment has not yet been continued long enough to provide sufficient data for a full statistical examination of seasonal fertiliser responses in relation to weather conditions, but in the meantime the general nature of the fertiliser responses on the two farms has emerged fairly clearly and the 19-year means are recorded in this preliminary statement.

It was soon apparent that nitrogen was by far the most effective nutrient on both farms and on almost all crops. The average responses to phosphate and potash were in general much smaller, although certain crops, notably potatoes at Rothamsted, gave big returns for potash and appreciable increases for phosphate. In Table 1 will be found the mean yields for all crops at the five levels of nitrogen, but for the much smaller effects due to phosphate and potash the mean linear regressions give a sufficient picture of the results, and these are therefore tabulated. For comparison the regression figures for nitrogen are also included.

At Rothamsted almost all crops show clear responses to nitrogenuous manuring. Thus 1½ cwt. sulphate of ammonia (the mean rate of dressing) gave increases of 0·74 tons sugar beet, 1·2 tons potatoes, 5·2 cwt. barley, 3·5 cwt. wheat, 5·7 cwt. rye per acre, but for clover hay the increases for nitrogen although appreciable are probably due in part to the presence of self-sown barley and weeds. For most crops there is a distinct falling off in the responses at the higher rates of fertiliser application. In rye straw and in particular in sugar beet tops the nitrogen responses are well maintained at the higher levels ; for the sugar beet tops the higher dressings appear to be if anything more effective than the lower ones.

At Woburn all crops except clover responded well to nitrogen. The increases for 1½ cwt. sulphate of ammonia were 1·6 tons sugar beet and potatoes, 7·7 cwt. barley, 3·5 cwt. wheat, and 4·9 cwt. rye. The actual responses were usually higher than the corresponding ones at Rothamsted, though the level of cropping was better at Rothamsted than Woburn. As at Rothamsted the increases tended

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to fall off at the higher levels, but once again sugar beet tops kept up their responses to the highest level of manuring. The nitrogen responses vary considerably from year to year. Taking sugar beet as an example, the most favourable year on both farms was 1943 when Rothamsted showed an increase in roots at the rate of 7·4 tons per 1 cwt. N, and Woburn 9·5 tons per 1 cwt. N; on the other hand in 1932 both farms showed a loss of 2 tons roots for 1 cwt. N, the worst result on record. The parallelism between the nitrogen effects at these two localities is by no means always as close as this; the nitrogen effects observed yearly at Rothamsted are much nearer to the general behaviour of nitrogen on sugar beet in the Eastern Counties, as measured by experiments carried out annually on commercial farms in all sugar factory areas, than are those at Woburn. In 1948 for instance, a year of low nitrogen response generally, Rothamsted gave practically no increase for nitrogen, while Woburn gave no less than 9·1 tons per 1 cwt. N.

As will be seen by the regressions, there are few striking responses to either phosphate or potash. The only crop that shows appreciable responses to phosphate is potatoes; this is found on both farms. Potash at Rothamsted gives a big response in potatoes, the successive increases over no-potash being 1·27 tons for ½ cwt. muriate of potash, 1·77 for 1 cwt., 2·07 for 1½ cwt., 2·43 tons for 2 cwt. muriate of potash per acre. In addition there is some evidence of a small response to potash in sugar beet and clover hay. At Woburn the small responses to potash in sugar beet and clover hay are very similar to these obtained at Rothamsted, but the potato crop behaves quite differently on the two farms. At Woburn 2 cwt. of muriate of potash gives only 0·3 tons of potatoes in contrast to the 2·4 tons obtained at Rothamsted.

The productivity of the two farms may be compared by examining the mean yield for each of the crops over the whole period of the experiment. Each crop had exactly the same manurial treatment on the same variety for the whole course of the experiment, except that from 1947 Squareheads Master wheat was substituted for Yeoman at Woburn on the grounds that it was more suited to the light soil. Rothamsted is on the whole the more productive farm, particularly for wheat where the yields exceed those at Woburn by 12·3 cwt. grain and 15·5 cwt. straw per acre; it also grows 0·81 tons more sugar beet with 3·23 tons more tops, and substantially more barley and rye. Woburn on the other hand gives somewhat bigger crops of clover hay and slightly more potatoes.

In Table 1 will be found the mean yield of each crop taken over three successive periods of six years. Such figures should reveal any pronounced tendency towards soil exhaustion during the course of protracted cropping with fertilisers alone, the only organic matter given being the sugar beet tops ploughed in on their respective plots. It should be noted however that certain changes in crop variety were made on both farms. In 1942 Majestic potatoes were substituted for Ally and in 1943 Kleinwanzleben sugar beet was substituted for Kühn. In other words during the last six-year period slightly heavier yielding varieties of roots were being grown, and in particular the yield of tops of the sugar beet might be expected to be appreciably increased by the change from Kühn to Klein-

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TABLE 1

Mean yields per acre at 5 nitrogen levels, Rothamsted and Woburn 1930-48

	Nitrogen cwt. per acre	Sugar Beet Roots tons	Sugar Beet Tops tons	Sugar Beet Total Sugar cwt.	Barley Grain cwt.	Barley Straw cwt.	Clover Hay Dry Matter cwt.	Wheat Grain cwt.	Wheat Straw cwt.	Potatoes Total Tubers tons	Rye Grain cwt.	Rye Straw cwt.
Rothamsted	0	7·98	7·57	28·8	25·9	28·3	22·1	24·1	34·5	6·48	19·8	35·1
	0·15	8·46	8·15	30·7	28·9	32·1	24·5	26·7	40·9	7·06	22·8	38·1
	0·30	8·72	8·75	31·6	31·1	35·2	26·0	27·6	42·0	7·64	25·5	41·9
	0·45	9·01	9·47	32·3	32·2	37·1	27·6	27·9	44·8	7·91	27·2	45·2
	0·60	9·28	10·50	33·1	32·7	38·8	27·5	28·4	45·9	8·32	27·6	45·8
Woburn	0	6·56	4·59	23·5	15·3	23·9	28·5	11·4	20·1	6·40	13·4	22·7
	0·15	7·35	5·02	26·4	19·8	27·9	28·0	12·7	22·5	7·10	15·9	29·9
	0·30	8·11	5·66	29·0	23·0	30·5	26·6	14·9	29·0	8·03	18·3	33·4
	0·45	8·60	5·93	30·3	24·2	31·5	24·2	18·2	32·5	8·73	20·8	37·2
	0·60	8·73	6·34	30·6	25·1	35·5	27·2	18·2	34·0	9·27	22·1	39·2
Mean Yield :												
Rothamsted		8·72	8·65	31·4	30·4	34·5	21·4	27·5	43·3	7·69	24·5	41·1
Woburn		7·91	5·42	28·2	22·5	30·5	27·0	15·2	27·8	8·05	18·0	32·9
Increase for :												
1 cwt. N	Rothamsted ..	2·11	4·79	7·5	11·3	17·3	8·7	6·4	17·5	3·01	13·2	19·0
	Woburn	3·73	3·02	12·2	16·0	20·7	–4·2	12·8	25·2	4·90	14·9	26·9
1 cwt. P_2O_5	Rothamsted ..	–0·28	–0·42	–0·5	1·3	3·0	–0·2	0·0	0·9	0·91	–0·5	1·2
	Woburn	–0·37	0·16	–0·9	1·5	0·5	0·0	–0·7	–0·7	0·68	–1·1	–1·6
1 cwt. K_2O	Rothamsted ..	0·27	–0·38	1·8	0·0	1·8	1·8	0·4	1·0	2·27	–0·3	–0·9
	Woburn	0·45	0·37	2·3	0·9	0·7	1·8	–0·3	–0·7	0·29	–0·2	0·5

Six Course Rotation. 6 year means

Yield per acre

	Sugar Beet Roots tons	Sugar Beet Tops tons	Sugar Beet Total Sugar cwt.	Barley Grain cwt.	Barley Straw cwt.	Clover Hay Dry Matter cwt.	Wheat Grain cwt.	Wheat Straw cwt.	Potatoes tons	Rye Grain cwt.	Rye Straw cwt.
Rothamsted											
1931–1936	7·68	8·43	27·1	28·6	36·3	14·4†	23·2	41·7	6·80	22·5*	45·7*
1937–1942	8·75	8·79	31·7	31·2	33·3	23·6	28·4	40·6	7·48	23·4	35·5
1943–1948	10·10	8·62	37·1	31·8	34·3	21·4	30·8	43·5	9·01	26·6	44·5
Woburn											
1931–1936	7·88	6·67	26·8	23·9	39·5	23·0‡	12·2	26·0	8·13	20·2*	36·8*
1937–1942	7·58	4·79	27·6	23·9	27·8	29·9	19·5	30·2	7·39	19·8	33·8
1943–1948	8·92	4·69	32·6	20·1	23·1	26·9	13·4†	26·9†	8·09	15·2	30·0

* 3 years only. † 4 years only. ‡ 5 years only.

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wanzleben. These changes may have tended to obscure in part any deterioration in fertility as far as the roots were concerned.

Taking the crops in which little or no change was made, namely barley, wheat, and rye, it appears that at Rothamsted the last six-year period gave better yields than either of the two preceding periods. Wheat in particular was much better at the end than at the beginning of the experiment. The yield of cereal straws showed a depression in the middle period, especially in rye, but recovered in the final period. At Woburn barley and rye showed a fairly marked decline in yield in the final six-year period, amounting to 3·8 cwt. and 5 cwt. grain respectively, the reduction in straw was even more marked. There was no definite trend in wheat yields at Woburn, where the level of production was low in any case.

Woburn Ley-Arable Experiment, 1938-1948

In 1938 a long period rotation experiment was begun at Woburn to test the effects on soil fertility of leys, lucerne and different systems of arable cropping. The cropping schemes under test are :

1. A three-year ley, grazed by sheep.
2. Lucerne, cut for hay for three years.
3. An arable sequence with one-year seeds : potatoes, wheat, one-year ley for hay.
4. A purely arable sequence without ley : potatoes, wheat, kale.

The results of these four methods of cropping the land are measured in two test crops, potatoes followed by barley. There are thus a series of five-course rotations in which the fourth and fifth crops are always potatoes and barley. There are five blocks, each of eight main plots, on four of these plots the above four cropping systems are tested without change to bring out cumulative effects. Since it is possible that some of the continuous rotations might lead to rather large differences in fertility, as for example by the exhaustion of organic matter, the remaining four plots carry the ley and arable sequences alternately, thereby testing the effects of the cropping at a steadier fertility level. The blocks were started off at yearly intervals so that after five years all phases of the rotations were represented annually. The only manurial factor in the experiment is the effect of 15 tons of dung per acre applied to the potato test crop. Its residual effects are followed through the subsequent crops. The dung treatments are repeated on their respective plots. Phosphate and potash applications are equalised for all treatments over a five-year period, but nitrogenous manures are applied according to a schedule based on crop requirements. Certain modifications in cropping have taken place in the course of the experiment. Kale was never a very satisfactory crop at Woburn, mainly owing to damage by birds and vermin, and in 1945 it was replaced by sugar beet. In 1940 Italian ryegrass was included in the mixture for the three-year ley to add bulk to the produce of the first year. In the autumn of 1948 rye was introduced in place of wheat, on the grounds that it was a more suitable crop and less damaged by birds.

To illustrate the information that becomes available as the experiment proceeds we may take the sequence on the first block

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started in 1938. For the three years 1938-40 the eight plots of this block carried each of the above treatments in duplicate, since at this stage there is no difference between continuous and alternating treatments. In 1941 potatoes were grown on the whole block, but each potato plot was split to test the direct application of 15 tons of dung per acre. The effect of the previous cropping was therefore measured in presence and absence of dung on a basis of two plots per treatment. In 1942 barley followed potatoes to give the second year effects of the treatment crops and the residuals in barley of dung applied to the previous potatoes. In 1943 the distinction between the continuous and alternating rotations began to operate on the first block. For example, of the two plots which had previously tested lucerne residues in barley, one went back into lucerne to give the continuous lucerne treatment, while the other changed over to an arable rotation beginning with potatoes in 1943. All the main contrasts are tested at all stages of the rotation every year, but there are only a few plots for each contrast in individual years. In presenting results over the period 1941-8 in Table 2, the continuous and alternating rotations have been taken together.

The level of potato yields in Table 2 is high and the standard errors year by year have been satisfactorily low. Barley has produced only moderate crops and, largely owing to game damage, yields have been much more variable. The wheat yields are low. The effect of the previous rotations on the yield of the test crops in the absence of dung may first be considered. The potato test crop receives a basal dressing of 0·6 cwt. N, 0·5 cwt. P_2O_5 and 0·75 cwt. K_20 per acre. In spite of this fairly generous treatment there is a considerable difference in yield due to the previous sequence of cropping. The residues of the ley give the best result with the very creditable average yield of 12·3 tons per acre. Lucerne is only half a ton behind, but the two arable rotations give significantly lower yields, the hay rotation being somewhat better than one with tillage crops. The difference in yield between potatoes following ley and those following arable crops is no less than 2·3 tons per acre. The barley crop, which follows potatoes and receives 0·2 cwt. N per acre as a basal dressing, gave a significantly better yield after lucerne than any of the other rotations. One year later the plots come into potatoes, which again receive the same fertilizer treatment as before. Yields are still good and at this stage the residues of the three-year ley stand out above all the other treatments. The same result is obtained with wheat in the fourth year when the effect of ley was significantly better than that of either of the arable rotations.

Direct dunging or dung residues has shown certain differential effects. In the first year when a direct application of dung is made to the potato test crop, the increase produced by the farmyard manure on the crops after ley is only moderate, about 1 ton per acre, but when the potatoes follow either lucerne or the arable rotations the dung effect is large, over 2 tons per acre. It is possible that the ley residues leave a better soil structure and the lucerne more available nitrogen. In barley the only case of a significant increase due to dung occurs after the arable rotation with hay, the dung raising yield to about the value produced by the other treatments. In spite of the poor residual effect in barley the effect

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on potatoes of dung applied two years previously is large after lucerne and small after ley. On wheat in the fourth year, the residual dung effect is small. Effective as dung has been on both potato crops, it has not masked the larger differences between the after effects of ley rotation and arable rotation.

Over the whole four-year sequence of test crops the position may be examined by averaging the two potato crops and the two grain crops.

Average of two potato crops, tons per acre; and two grain crops, cwt. per acre:

	Ley	Lucerne	Arable with hay	Arable without hay
Potatoes without dung ..	11·8	10·9	10·1	9·9
,, with dung	12·6	13·2	11·9	11·4
Grain without dung	15·6	16·3	12·6	13·8
,, with dung	15·7	16·0	15·1	15·2

Without dung ley produces considerably more potatoes than any other treatment, lucerne also gives more than either of the arable rotations. The grain yields are also in favour of the ley and lucerne treatments. When a dressing of dung is given to the first potato crop lucerne gives slightly more potatoes than ley, and both of them much more than the arable rotations. The grain yields are in the same order but show much smaller differences.

For both kinds of test crop the yields without dung after leys are similar to those with dung after arable crops.

Productivity of Treatment Crops

The lucerne plots are cut green and their production of dry matter for each cut is calculated. Sample cuts are taken from the ley plots immediately before the sheep are put in. A record is also kept of the number of grazing days per plot per season. For each of the years 1945-48 there are first, second and third year yields of ley and lucerne. The figures are as follows:

	Lucerne Hay tons per acre		Three years Ley Dry matter in sample cuts, tons per acre		Sheep Grazing days per acre	
	Mean	Effect of residual dung	Mean	Effect of residual dung	Mean	Effect of residual dung
1st year	0·50	0·07	1·59	0·00	607	6
2nd ,,	2·64	0·17	4·32	0·42	1700	—3
3rd ,,	3·16	0·27	5·15	0·77	1782	—21
Total	6·30	0·51	11·06	1·19	4089	—18

In terms of dry matter per season the leys gave very high yields, 11 tons of dry matter over the three years, and were much more productive than the lucerne under the system of management adopted. This was particularly noticeable in the first year. The residual effect of dung applied two years previously was small, the leys proving more responsive than the lucerne. The yield of continuous lucerne as compared with lucerne alternating with an arable rotation was examined in the years 1945-48 in which comparisons within blocks was possible.

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	Lucerne Hay : tons per acre	
	Following 3 Years Lucerne	Following 3 Years Arable Rotations
1st year	0·51	0·42
2nd ,, ...	2·84	2·70
3rd ,, ...	3·31	3·47
Total	6·66	6·59

At this early stage there was no indication that the previous lucerne had any bad effect on the following lucerne.

TABLE 2

Mean yields of	After 3 year's cropping with				
	Ley	Lucerne	Arable with Hay	Arable without Hay	Standard Error
1st Year (1941-48)					
POTATOES. Tons per acre					
No dung	12·3	11·9	10·6	10·0	±0·22
Dung to potatoes	13·4	14·1	12·7	12·0	±0·22
Mean	12·9	13·0	11·6	11·0	±0·18
Increase for dung	1·1	2·2	2·1	2·0	±0·26
2nd Year (1942-48)					
BARLEY. Grain cwt. per acre					
No dung	17·4	20·5	16·2	17·8	±0·84
Dung one year before ..	17·5	19·8	19·6	18·6	±0·84
Mean	17·4	20·2	17·9	18·2	±0·60
Increase for dung residues ..	0·1	–0·7	3·4	0·8	±1·17
BARLEY. Straw cwt. per acre					
No dung	23·0	24·3	19·6	22·0	
Dung one year before ..	22·8	25·2	25·2	23·4	
Mean	22·9	24·7	22·4	22·7	
Increase for dung residues ..	–0·2	0·9	5·6	1·4	
3rd Year (1943-48)					
POTATOES. Tons per acre					
No dung	11·2	9·9	9·6	9·8	±0·46
Dung two years before ..	11·8	12·1	11·1	10·8	±0·46
Mean	11·5	11·0	10·3	10·3	±0·36
Increase for dung residues ..	0·6	2·2	1·5	1·0	±0·58
4th Year (1944-48)					
WHEAT. Grain cwt. per acre					
No dung	13·9	12·1	9·0	9·8	±1·23
Dung three years before ..	13·9	12·3	10·6	11·8	±1·23
Mean	13·9	12·2	9·8	10·8	±0·97
Increase for dung residues ..	0·0	0·2	1·6	2·0	±1·50
WHEAT. Straw cwt. per acre					
No dung	29·2	22·5	19·9	21·6	
Dung three years before ..	27·9	23·6	20·7	26·9	
Mean	28·5	23·1	20·3	24·2	
Increase for dung residues ..	–1·3	1·1	0·8	5·3	

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Rothamsted Ley-Arable Experiment, started 1948

After eleven years experience with the ley-arable experiment at Woburn, two similar but more comprehensive experiments were begun at Rothamsted in the autumn of 1948. The general purpose is the same as at Woburn, but since permanent grass plots are included it will be possible in the newer experiments to compare the two systems, permanent grass plus permanent arable, with alternating grass and arable. There are also additional cropping and manurial treatments included, and the productivity of the grass is estimated by the live weight increase and grazing days of sheep as well as by sampling methods. Moreover the Rothamsted experiments provide a direct comparison of the output from permanent grass as compared with temporary grass under the same conditions; and in one of the experiments a comparison of old permanent grass with reseeded permanent grass. The experiments have been started on two fields: (1) Highfield, on part of the land formerly occupied by the R.A.S.E. grazing experiment. This is a very old grass field and the new experiment has been established on the ploughed up turf. (2) Fosters Field, an old arable field. The treatments whose output and effect on soil fertility are under test are:

1. Three year ley, grazed by sheep.
2. Three year cut grass, as for drying.
3. Three year lucerne, cut as for hay.
4. Three year arable rotation: one year seeds for hay, potatoes, barley.

The three test crops which follow all the above preparatory treatments are wheat in the first testing year, potatoes in the second year, and barley in the third. Outside this sequence of treatment crops and test crops there are permanent grass treatments: on Highfield (1) old grass and (2) reseeded grass. On Fosters reseeded grass only. All the permanent grass plots are grazed with sheep for two years and hayed in the third year. The experiment on Highfield is set out in 6-plot blocks and on Fosters in 5-plot blocks. Each plot in a block is assigned to one of the rotation or permanent grass treatments. The method is illustrated by the following scheme showing the cropping in the 6-plot blocks of Highfield commencing in 1949 and covering the first six-year cycle.

Phase A	Phase B	Plots (1)	(2)	(3)	(4)	(5)	(6)
1949	1952	L	Lu	CG	H	G	R
1950	1953	L	Lu	CG	P	G	R
1951	1954	L	Lu	CG	B	G	R
1952	1949	W	W	W	W	G	R
1953	1950	P	P	P	P	G	R
1954	1951	B	B	B	B	G	R

L = 3-year ley Lu = lucerne CG = cut grass
G = old permanent grass R = reseeded grass
H = 1 year arable hay P = potatoes
B = barley W = wheat

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There are two blocks started in phase A (treatment crops followed by test crops) and a further two blocks in phase B which is three years behind phase A and leads off with the three test crops before the treatment crops come into operation. In 1949 there will thus be four blocks started as above in each field; on Fosters there is no treatment G, but otherwise the arrangements are the same. In 1950 an exactly similar set of four blocks will be started in each field, and again in 1951, when all six stages of all the rotations will be represented in duplicate. In 1952 measurement fertility effects built up by the leys, lucerne and other treatment crops, will begin in the test crops on two blocks in each field.

Manuring: Phosphate and potash in the form of a compound fertiliser with 13% P_2O_5 and 13% K_2O are applied in standard amounts to all crops according to their requirements in dressings providing in all 2·4 cwt. P_2O_5 and 2·4 cwt. K_2O per acre over the six-year cycle. The manurial tests are made on nitrogen fertiliser and dung. The treatment crops are grown at two levels of nitrogenous manuring appropriate to the crops (lucerne has no nitrogen); and the effects of the crop grown at each level of manuring is measurable at two nitrogen levels in the subsequent test crops. The schedule for nitrogen application is as follows:

Crop	N cwt. per acre Low Level	High Level	Applied
Wheat	0·3	0·6	Spring top dressing.
Potatoes ..	0·5	1·0	In ridges.
Barley	0·2	0·4	In seedbed.
One year Hay ..	0·3	0·6	Early spring.
3 year Ley ..	0·15	0·3	Every year—half in spring, half in summer.
Cut Grass ..	0·15	0·3	In early spring and after 1st, 2nd, 3rd cut yearly.
Lucerne ..	none	none	
Permanent Grass / Reseeded ..	0·15	0·3	Yearly. In the first two years in divided dressings (half in spring, half in summer); in the third (hay) year in a single early spring dressing.

Dung is also tested at 15 tons per acre in the ridges on potatoes both in the arable rotation and as the test crop. It is applied on quarter plots to show the combinations of dung and levels of nitrogen (O v D) (N_1 v N_2). As the experiment develops the dressings of dung are arranged on the sub-plots so as to bring out direct, cumulative and residual dung effects. The size of the main plots is 1/11 acre, the largest obtainable in the fields in question. When the experiment is fully started there will be 72 of these main plots on Highfield and 60 on Fosters. Fertiliser effects of nitrogen and dung are measured on a quarter plot basis, except that on permanent and reseeded grass and three-year ley the grazing unit which tests the direct effect of nitrogenous applications is a half-plot of 1/22 acre.

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Irrigation Experiments, 1947 and 1948

At the request of the Sugar Beet Research and Education Committee of the Ministry of Agriculture, Rothamsted undertook the control of experiments on the irrigation of sugar beet. Members of the Physics and Chemistry departments and the Field Experiments Section took part in the work.

A preliminary trial took place in 1947 on the farm of Mr. F. A. Secrett at Milford, Surrey, and in the following year a much bigger experiment was laid down on the same farm.

The main points in regard to these two trials are briefly recorded below.

The soil at Hurst Farm, Milford, is a deep sandy loam derived from the Greensand formation. It is intensively manured for market garden crops with bulky and concentrated organic manures and also fertilizers. Overhead irrigation with oscillating spray lines is an essential part of the system and for certain crops a very dilute solution of potassium nitrate (one part in at least 5000 parts of water) is applied through the spray lines instead of pure water.

In 1947 half an acre of sugar beet was drilled after a crop of spinach had been harvested. This small area was used for a pilot experiment whose main object was to gain experience of the practical problems arising in the carrying out of irrigation trials. Two plots each of $\frac{1}{6}$ acre received the irrigation, four others of 1/24 acre were dry controls. The provision of water was from the main commercial installation, which was naturally being used simultaneously in other parts of the farm, consequently strict control of water supply, and more particularly of the supply of nutrients in the water was difficult to achieve. The treatments were:—

1 and 2	No water.
3	Irrigation with water only.
4	Irrigation with water containing potassium nitrate.
5 and 6	No water, but dry potassium nitrate top dressed in amount equivalent to 4.

The season was a particularly dry one especially in summer and autumn. The period July-October inclusive gave only 3·3″ rain, whereas the average for 55 years in the neighbourhood was 10·1″.

On June 25th irrigation started. The crop at this time was a practically perfect plant, 35,000 per acre, in full vigour of growth, with the promise of very heavy yields. Seven irrigations in all at approximately fortnightly intervals were given ending on September 26th, the total quantity of water applied being approximately 10″. In the very dry summer weather the effects of the water were visible three days after application, and showed in larger leaf area and brighter and fresher leaf colours. The crop was lifted on November 4th. The dry potassium nitrate application, and the potassium nitrate applied in the irrigation water, estimated as 121 lb. per acre, had effects so small that in a non-replicated trial they might easily occur by chance, so they are omitted for the following presentation of the main results.

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	Dry plots (1, 2, 5, 6)	Irrigated plots (3, 4)	Effect of 10″ water
Clean roots tons per acre	20·10	29·76	+9·66
Sugar per cent	19·22	16·71	—2·51
Sugar cwt. per acre ...	77·3	99·5	+22·2
Tops tons per acre ...	9·25	14·48	+5·23
Plants thousands per acre	35·6	34·4	—1·2
Noxious N	43	42	—1

There was a first rate crop without irrigation, a result largely due to the very high plant population. In this dry summer the effect of watering was very striking indeed, it increased the yield of clean roots by 9·66 tons to give the astonishing figure of nearly 30 tons per acre. It increased the average root weight from 1·26 lb. to 1·94 lb. The sugar content of the roots was depressed by watering to the extent of 2·5 per cent. There was a gain of 22·2 cwt. sugar per acre. Tops on the dry plots were fairly heavy for such a droughty year, but they were increased by a further 5·2 tons by irrigation. Plant number and noxious nitrogen were practically unaffected.

In 1948 a much larger experiment was put down on the same farm, in this case on a field that had recently been taken over and never before irrigated. It had not received the long course of heavy manuring practised on the older land. A special pumping plant was installed completely under the control of the experimenter, the water being supplied from a nearby lake. Arrangements were made for the introduction of dilute potassium nitrate solution into the water system as required. A full time supervisor, Mr. A. B. Venables, was seconded from the British Sugar Corporation to take charge of the experiment. A meteorological station was set up on the plots and a small laboratory for nitrate determinations.

The design of the experiment was a six by six Latin Square with plots of $\frac{1}{16}$ acre to carry the irrigation treatments. Within each main plot 4 sub-plots tested supplementary fertilizer treatments with nitrogen and potash. The basal treatment was 30 tons of dung per acre applied in January 1948, and 7 cwt. I.C.I. compound fertilizer No. 1 containing 12% N; 12% P_2O_5; and 15% K_2O with 3 cwt. agricultural salt per acre in addition.

The treatments were:—

Main plots:—

1 and 2 No water
3 Full irrigation at Mr. Secrett's discretion
4 As 3 with dissolved potassium nitrate
5 Restricted irrigation based on climatic data
6 As 5 with dissolved potassium nitrate

Sub-plots:—

a. No additional fertilizers
b. 2 cwt. of nitrate of soda per acre
c. 1 cwt. of muriate of potash (60%) per acre
d. Nitrate of soda + muriate of potash

The crop was sown very early (March 23rd) and singled (April 27th) and almost immediately suffered from a bad attack of fleabeetle which was energetically combated by dusting, but none

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the less some plants were lost. The result was that the plant population was 29·2 thousand instead of the 35,000 attained in the previous year. Subsequently the crop grew exceedingly well without any checks apart from a severe infestation with virus yellows. The crop was lifted on October 18th while still in full growth.

The season was in great contrast to the previous year as the following figures show:—

	Rainfall inches 1948	1947	Excess in 1948
May	2·06	1·67	0·39
June	2·60	2·14	0·46
July	0·96	1·06	—0·10
August	4·02	0·52	3·50
Total	9·64	5·39	4·25

The summer of 1948 was dull and distinctly wetter than 1947, particularly in August. There was a dry period in early May at the time of the beetle attack and a second dry period in July.

Full irrigation with and without salts was given on 6 occasions, starting on 12th May and finishing on 30th July to provide a total of 4·7″ water. Restricted irrigation with and without salts was applied on three occasions May 22nd, July 18th, and August 4th to a total of 2·6″. The salts included in the irrigation water were estimated at 83 lb. per acre for the full and 59 lb. for the restricted irrigation. These salts at most supplied 11 per cent of the nitrogen and 33 per cent of the potash given in the basal dressing. The effects of irrigation were seldom apparent in the cool, dull summer of 1948, only on one occasion during a hot spell in July it was noted that the dry plots were wilting while the irrigated plots were not. The results were as follows:—

Sugar Beet, Milford, 1948

Effect of irrigation ; dissolved salts, fertilizer N and K

(Each set of comparisons averaged over all other factors)

	Water, inches 0	2·6	4·7		Increase for dissolved KNO_3		Increase for 2 cwt. Nitrate of Soda	1 cwt. Muriate of Potash	
Clean roots tons/acre ..	22·0	22·6	21·9	±0·19	−0·2	±0·26	−0·4	0·2	±0·18
Sugar percentage ..	14·9	14·7	14·7	±0·37	−0·1	±0·52	−0·3	0·2	±0·09
Sugar, cwt./acre ..	65·5	66·7	64·1	±0·76	−0·8	±1·07	−2·5	1·3	±0·68
Tops, tons/acre ..	30·6	31·6	32·8	±0·35	−0·2	±0·50	1·4	0·2	±0·23
Plant No., thous./acre ..	29·0	29·5	29·2	±0·29	−0·6	±0·41	−0·2	0·2	±0·22

There were 22 tons of clean roots per acre with the rather low sugar content of 14·8 per cent, giving a mean sugar production per acre of 65·4 cwt. The plant number at 29 thousands was high, but considerably lower than the perfect plant secured in the year before. The tops at 31 tons were the heaviest ever recorded in any Rothamsted experiment. The precision was satisfactory.

Watering did practically nothing so far as yield of sugar per acre was concerned under the conditions prevailing in 1948. It tended to reduce the sugar content of the roots and increased the top yield significantly. Plant number was unaffected. The effect of added

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salts was small and non-significant. Fertilizer nitrate of soda reduced the yield of roots and the percentage of sugar significantly. As usual nitrogen increased the top yield. Muriate of potash gave a slight increase in sugar per acre. There were no significant interactions between any of the treatments.

So far as they have gone these preliminary trials have encountered extreme conditions under which water either gave an enormous increase or practically no increase at all. They have been valuable in enabling a start to be made on working out the technique of such trials. Two further experiments are being laid down for 1949.

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THE FARMS

By J. R. MOFFATT

Rothamsted

The year 1947–48 has brought no major changes in policy, staff or buildings, and has been a period of settling down under post-war farming conditions.

The acreage farmed was reduced to 474¾ acres by relinquishing 26 acres of rented grazing land (for sports grounds) and also 5 acres of rented arable, although an extra 2½ acres of grassland were taken in. The main arable crops were wheat (95 acres), barley (58 acres), oats (16 acres), potatoes (34 acres). Other crops included linseed, sugar beet, beans, peas, rye, mangolds, and kale. The area of permanent grassland was 103 acres, most of which was either under long-term experiments or was unploughable because of tree stumps. 86 acres were under temporary leys. The only big difference between 1947 and 1948 cropping was that the proportionate areas under wheat and barley were reversed.

The number of experimental field plots decreased from 1479 in 1947 to 1412, which proved almost as many as could be handled successfully under the bad harvesting conditions. One bean experiment was destroyed by birds, and the severe attack of fleabeetle on the linseed reduced the value of one experiment as the late-sown plots were destroyed. The main factor limiting the number of corn plots is the bottle-neck caused at harvest by all winter and spring sown cereals and pulses needing to be harvested within a short space of time, but when a small combine harvest suitable for use on small experimental plots is available, it may be possible to raise the limit. With root crops, the limiting factor is the labour available for singling. For some years past much of this work has been done by labour gangs from the Agricultural Executive Committee, but since the repatriation of the German prisoners-of-war, this source is likely to dry up, and may result in a reduction in the acreage of root crops which can be handled.

Details of the field experiments are given in the report of the Field Plots Committee.

The severe drought experienced during the summer of 1947 continued until early December of that year, and it was not until the middle of that month that moisture reached ploughing depths. Land work in the autumn was pushed ahead as far as the hard dry conditions allowed. The drilling of the winter corn, which had to be delayed because of the very dry state of the ground, was completed early in November. Eleven acres were sown to winter beans, but birds destroyed the whole area on which the beans were drilled, but did little damage where the seed was ploughed in. In the latter half of December and throughout January, 1948, the rainfall was heavy. Very few frosts occurred during the winter, and none of any severity, and the mean temperature for January was 4° F. above the average.

Weather conditions during spring were very favourable to farm work; the rainfall for February, March, and April was well below average, while the mean temperatures were well above. Land

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operations started on March 2nd, much earlier than usual, and continued almost uninterrupted until all sowings were completed. Good seedbeds were obtained reasonably easily, and the seeds germinated rapidly and evenly.

The very mild weather caused fleabeetles to become active far earlier than usual and their attacks persisted throughout the latter half of April and all of May. Severe damage was done to several crops; the first sowing of kale was completely destroyed and the second only survived after repeated dustings with benzene hexachloride; the first sowing of mangolds in Barnfield was so badly damaged, despite repeated dusting, that the whole area had to be resown; the sugar beet, which was sown early under good conditions, was severely attacked, and although several dustings saved the crop. growth was severely retarded and the singling stage was not reached until later than usual. The linseed was also badly attacked, and although repeated dustings saved the main area, the experiment comparing early and late sowings was spoilt as the beetles concentrated on the late-sown plots and destroyed most of the plants.

Wireworm damage, although not severe except on one field where an experiment was carried out to control the pest, was much more widespread than usual. Preliminary reports on the experiment indicate that seed dressing against wireworm may become a practical possibility within the next few years.

The season was a favourable one for the growth of weeds. The early preparation of the seed beds and the warm spring encouraged a widespread germination of weed seeds, while the moist weather in May and June enabled them to grow fast and compete strongly with the crops. The hoes had to be kept going continuously, as many of the hoed weeds took root again in the moist soil. Many of the cereal crops were sprayed against weeds, and gang labour was employed to side-hoe the root crops. On Broadbalk field the infestation of weeds was the worst for many years, but the permanent barley plots on Hoosfield provided a happy contrast, the corn being so much cleaner than usual that the annual spraying operation was not needed. Wild oats seem to be spreading from the permanent wheat and barley plots over much of the farm, and on one wheat field the infestation was particularly severe.

The rainfall during the latter half of May and throughout June and early July was heavy, and temperatures were below average. The cereal crops, sugar beet and potatoes grew vigorously under these conditions and looked very promising. Cereal crops became longer in the straw than usual, which led to some lodging before the end of July, while ripening was delayed by the dull cool weather during that month.

The weather conditions at the start of harvest were atrocious, and the work was very seriously delayed. The heavy rainfall early in August caused many areas of barley to become badly lodged, but fortunately most of the wheat and oats remained standing. Moulds formed very rapidly on the wheat ears, and what at one time promised to be an excellent harvest degenerated into a rush to harvest as much as possible before too much deterioration took place. Fortunately the weather improved in September, and enabled all the experimental corn plots and most of the non-

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experimental corn to be carted in fairly good condition and stored in the Dutch barns. Only a few outside stacks were built, and these were threshed soon after harvest was completed. Yields of the major crops were as follows: wheat, 24 cwt. per acre, barley, 26 cwt. per acre, and oats, 19 cwt. per acre.

The wet weather in early August caused Late Blight to appear on the potatoes, and despite spraying against the disease and burning off the tops with sulphuric acid before lifting, some lesions appeared on the tubers when they were lifted. The Scotch A seed used was disappointing in that many of the tubers were affected by Dry Rot, which caused several blanks in the rows. The harvesting of the crop was spread over a longer period than usual because of the heavy yield and the short hours worked by the school children who did most of the picking, but fortunately the weather remained reasonably good. The tubers were large, but of good shape with few blemishes. The yield from the non-experimental areas was estimated at about 14 tons per acre, but the highest individual plot yield was 23·8 tons per acre, with a percentage ware of 94·2. Lifting was completed in the last week of October and as usual the crop was stored in heaps to a depth of 12–14 ft. within straw bale walls under the Dutch barns. It was very difficult to dispose of the crop, but fortunately they stored very well, and most of them were eventually sold to the Ministry of Food. The two main non-experimental areas were granted an English H seed certificate, and some of the crop will be planted in 1949 at Rothamsted and Woburn.

The protracted potato harvest delayed the preparation of the winter corn seed beds, and the lifting of the mangold and sugar beet crops. In the past few years, labour for both these operations has been supplied by the County Agricultural Executive Committee, but in 1948 this labour was no longer available. These operations therefore took longer than usual, as they had to be carried out mainly by the regular staff. Fortunately the weather remained open and the mangolds were harvested without being damaged by frost. The lifting of the sugar beet was not finished until just before Christmas, as the damp conditions made the roots difficult to clean and the land sticky. Yields were well above average, the best individual plot treatment yielding over 20 tons of beet per acre.

Grassland

The weather throughout the year was very suitable for grassland. Growth started early and was maintained throughout the year, and extra cattle were needed to keep the grass properly grazed. Hay-making was a very tedious operation, for in the dull, cold weather of June and early July the hay remained at the same stage for days on end, but it was all carted by mid-July. Yields were well above average and the quality was quite fair.

The grazing experiment in High Field comparing the manurial value of feeding stuffs with the conventional estimate of their value applied as fertilizers was concluded in the autumn of 1948.

Implements

The main acquisition during the year was a small 5 ft. cut combine harvester which was used during the 1948 harvest for the first time. It proved very satisfactory, tackling the laid crops of

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barley very well and considerably reducing the losses due to shed grain. It could only be worked for a limited period because of the damp conditions and the lack of a grain drier. The machine was tested out for harvesting experimental plots, but did not prove satisfactory for this work.

A few other implements were purchased to replace similar old equipment.

Buildings

No additions or alterations were made to the buildings at the farmstead, but six new cottages for the farm workers were completed. The new concrete road between the farm and the laboratory was also completed during the year.

Livestock

Cattle. The shortage of grass during 1947 reduced the number of cattle which could be fattened from the grass that year. Most of those left were brought under cover during the winter of 1947–48 and kept on hay and barley straw with a small supplement of concentrated foods. They were fattened on the grass during the summer and autumn, and an extra bunch of Irish beasts were purchased in the late spring and finished on the grass. By September 30th, 1948, some 40 beasts had been sold fat, and in that autumn they were replaced by another bunch of Irish cattle. Another 25 cattle are almost ready, and will be sold before the end of the year.

Sheep. Because of the high cost of Scottish Halfbred gimmers, no additional breeding sheep were purchased, although some of the best of the home-bred ewe lambs were saved for breeding. The flock is therefore now rather mixed, consisting of 75 Halfbred ewes, 6 Hampshire ewes, 34 home-bred ewes (Oxford x Halfbred) and 65 ewe lambs of the 1947 crop, of which about 30 had lambs by a Suffolk ram. All except ewe lambs were mated to Oxford rams for the production of fat lambs. The lambing percentage was 131, rather lower than usual, but the abundance of grass enabled the ewes to milk well and their lambs made good progress throughout the season.

Feeding stuffs

The farm has again been independent of purchased feeding stuffs except for those foods allotted to us in return for sugar beet and linseed sold off the farm, and molasses for feeding with straw.

The year on the farm can on the whole be regarded as satisfactory, although what promised to be a bumper corn harvest was partly spoilt by bad weather just before the harvest. For all other crops the season was a good one once the initial difficulties caused by pest damage and weed competition were overcome.

Woburn

This account of the year's activities covers the second year in which the direction and management of the Rothamsted and Woburn Farms was merged. Many of the objectives of the first year of merged direction were thwarted by the very abnormal weather conditions in that year, but changes in cropping, manuring

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and livestock policy were made. The most urgent tasks not fully achieved were the need to clean the land and increase its productivity, and to increase the mechanization of the work.

Cropping

The area farmed during the year remained at 128¾ acres, of which 53¾ acres were under cereals, 15½ under potatoes, 10¼ under sugar beet and 10 under linseed. About 11¼ acres were bare-fallowed, 4½ were under sundry experimental crops, and the remaining acreage under grass. 23 acres of old grassland were broken up during the year. The number of experimental field plots was increased by the inclusion of sugar beet experiment testing the effect of plant density on the spread of Virus Yellows disease and two experiments testing various manurial and cultural effects on linseed. These brought the total plot numbers to 530, although the yields on the sugar beet experiment were not taken.

Effect of Weather on Crops

The season opened inauspiciously, as the severe drought of the summer of 1947 continued throughout the autumn of that year, and many fields remained so hard that the preparation of the land for winter wheat was prevented. Ploughing however was possible during December 1947 and early January 1948, but then a period of very heavy rain stopped land work and gave a rainfall figure for the month of 4·26 in. Conditions soon improved and field work was got up to schedule by the end of February. Conditions in March were very favourable, for only 0·66 in. of rain fell, while the average temperature remained well above average, so the sowing of spring corn started earlier than usual. The favourable weather continued throughout April, and this enabled more time than usual to be spent on the preparation of seedbeds. All the areas for root crops were ploughed twice, while some of the twitch-ridden land was ploughed three times. By the end of April, all spring cereals, linseed, potatoes, sugar beet, red beet, peas, cabbages and leeks had been sown, as well as all undersown grass and clover seeds and green manure crops.

The warm spring weather encouraged the germination of crop seeds, but unfortunately had a similar effect on weed seeds. The wet weather which followed in May and June enabled the weeds to grow rapidly and compete strongly with the crops. In the dry summer of 1947 the number of weeds which germinated was low, and it is probable that in 1948 a bigger proportion than usual of weeds germinated. MCPA weed-killer in powder form was used very successfully in the cereal crops, but much extra hand and horse labour was needed in the small experimental areas, to keep the weeds under reasonable control. The experimental pea crop presented very great difficulties, and despite every effort, the prevalence of weeds must have affected the yield of this crop. Trials were carried during the season with a number of small motor hoes, and one was found which should considerably reduce the amount of hand labour needed in future on experimental plots.

The permanent wheat and barley plots in Stackyard field were fallowed in 1947 to eradicate twitch and wild oats, but owing to the dry summer there was a very poor germination of wild oats and it

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was decided to fallow these areas again in 1948. The wet and mild weather in late December 1947 and early January 1948 encouraged germination, and by continually working these areas throughout the season, several successive batches of seeds were encouraged to germinate, and it is hoped that a fairly high proportion of the seeds in the ground were destroyed.

The exceptionally warm weather in March and April caused the fleabeetles to become active far earlier than usual, and before the end of April, red beet and rape on experimental plots had to be dusted to save them from total destruction. The linseed areas were also badly attacked despite many dustings, and although sown early, while some plots which were not sown until later were checked in their growth until early June. These plots remained backward throughout the season and a number of plants were still in the flowering stage when they were cut in September. Wireworm damage was also fairly widespread, especially on spring cereals, but none of the attacks were very severe.

Game damage unfortunately was considerable. Two sowings of wheat on an experiment were destroyed, and other areas of wheat and barley were damaged. Moles were again active, but their numbers were greatly reduced by trapping.

The rainfall in May was almost twice the average, and in June, too, was well above average. This caused all crops to make very rapid growth, and the cereals, sugar beet and potatoes looked very promising throughout June and early July. Several patches of barley and much of the linseed became lodged later in the month, however, while low temperatures and lack of sunshine retarded the ripening of all crops. Conditions improved later in the month, but it was evident that harvest would be later than usual.

The early part of August produced extremely bad weather, and on one day there was a rainfall of 2·39 in., more than the average for the whole month. This increased the lodging of the barley and linseed crops, but the oats and wheat stood up quite well. Harvesting started on August 10th, but more heavy rain followed and further delayed this operation. The total rainfall for the month was 4·42 in. and September also had a fall well above the average; despite this, most of the crops were eventually secured in reasonable condition, although a considerable amount of barley was lost through lodging and shedding. The linseed was so badly lodged that it had to be cut by mower and carted loose, and this was accomplished in good conditions at the end of September. The yield of spring oats reached 30 cwt. per acre, but wheat and barley yields were lower than anticipated, the former averaging 22·2 cwt. per acre and the latter 20 cwt. per acre.

The potato crop, benefiting from early planting and suitable weather, grew well throughout the season. The crop was sprayed against Late Blight, and the haulm was burnt off with acid shortly before lifting. The lifting of the crop was an extremely slow job, partly because of the difficulty of obtaining sufficient labour at the start and partly because of the heavy crop, (the yield being estimated at 14 tons per acre over the non-experimental areas). The tubers were of good size and shape, with little damage by pests and less scab than usual, but there was a proportion of blighted tubers despite the precautions taken. The crop was stored in a building

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at the farmstead to a depth of about 11 feet from the surface of the heap. There proved to be an inadequate flow of air over the top of the heap, and this inadequate dispersion of warm and damp air resulted in the condensation of moisture at a depth of about 18 in. from the surface of the heap, and a band of potatoes at the centre had to be discarded when the potatoes were sorted. In future years the storage of potatoes will be on similar lines except that provision will be made for the adequate flow of air by adjustable shutters, and the drawbacks experienced this year should not recur. To expedite the handling of the 1949 crop, some form of elevator will be used, and it is also hoped that some degree of mechanisation of the harvesting process may be possible. The restriction on the sale of Majestic potatoes in Bedfordshire and the huge surplus of potatoes in the country as a whole have made it difficult to secure a market for the crop, and it has now been taken by the Ministry of Food for processing at sugar beet factories.

The shortage of skilled labour for singling the sugar beet crop necessitated the use of unskilled help for this work, which resulted in poor singling and poor control of weeds, while the very slow work caused costs to be high. However, by dint of a few skilled men working long hours of overtime, the beet area was kept reasonably clear of weeds and rapid growth was maintained. The harvesting of this crop was carried out mainly by the regular farm staff, although a few extra workers were obtained to complete the work by Christmas. Yields averaged about 13 tons per acre of washed beet, with an average sugar content of about 16·5 per cent.

The only tractor was engaged on potato lifting throughout October and early November; consequently no other land work was possible. Outside assistance was obtained for ploughing, and about 30 acres of winter corn were drilled by mid-November.

Grassland

All the grassland not scheduled for breaking up was dressed with basic slag during the winter of 1947–48, and nitrogenous fertilizers were used liberally later to ensure a good growth of grass throughout the season. Only a small area was cut for hay, but the wet summer and adequate supply of nitrogen produced a heavy yield which was made and carted in good condition.

Buildings

New implement sheds, tractor garages, and covered barn space are now urgently required, and although it has not been possible to erect these during the year, plans are now well advanced and it is hoped to have these new buildings erected during 1949.

Implements

The policy of re-equipping the farm with modern implements started in 1947, and there is now at the farm or on order a nucleus of essential equipment. However, much more requires to be done, especially with regard to implements required for the working of experimental plots, while a gradual replacement of old equipment by modern equipment will be continued. A second tractor will probably be ordered in 1949.

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Labour

The increased area under arable crops, and the increased production from the farm as a whole, has necessitated a larger labour force. It has been very difficult to recruit sufficient labour of the right type, and we have had to rely to a considerable extent on such casual labour as was available, and on the Agricultural Executive Committee's labour gangs. The position is aggravated by the fact that there are only two cottages on the farm, and it is difficult to secure labour unless accommodation can be provided. The position is a little easier than it was, but several of the workers now on the staff have to travel some distance, and it is unlikely that they will stay if work becomes available nearer their homes.

W. A. McCallum, the farm foreman, retired from this position at the end of September, 1948, and has been succeeded by A. W. Neill.

Livestock

Horses. The two old worn-out horses were disposed of, and a team of three grey Percheron-cross horses has been purchased. Most of the work on the experimental plots has been carried out by these horses.

Cattle. The eleven beasts which could not be fattened during the summer of 1947 because of the shortage of grass due to the very dry weather, were finished off during the summer of 1948. As much grassland had been ploughed up no other beasts were purchased until the autumn, when 12 cross-bred Hereford bullocks were bought.

Pigs. The Large White pig herd has done quite well, but because of the scarcity of feeding stuffs most of the pigs were sold as stores. In order to qualify for extra feeding stuffs under the new bonus scheme, the pig herd will be reduced somewhat and more of the pigs will be carried on to bacon weight.

Conclusion

The results of the season's work have been generally satisfactory, although the difficulties were increased by the prevalence of weeds, the bad weather conditions at harvest, and the difficulty of obtaining sufficient labour of the right type. As more equipment is obtained, it is hoped that the farm can be made less dependent on Rothamsted for equipment, and on casual workers for labour. There has been a big increase in labour costs during the year, and a much heavier expenditure on seeds and fertilizers, but the heavier outgoings are reflected in a very much increased valuation of crops.

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WOBURN EXPERIMENTAL STATION

By H. H. Mann

Season

The season of 1947–48 was a very wet one, the rainfall being higher than for several years. It amounted to 28·36 inches for 1948 and early in August we received the biggest amount of rain in a single day that has occurred for over twenty years (2·38 inches). The summer of 1948 was, in fact, a great contrast to that of 1947 when there was an almost complete drought during the growing season. The weather was also cold during the summer months, and very wet at harvest. These facts made the harvest, particularly of those crops which ripen in the autumn, very difficult.

Field Experiments

Wild oats are a serious pest on the permanent barley plots in Stackyard field. The long continued growth of barley on the same land had led to an extremely bad infestation of the area and to the necessity of fallowing the ground for long enough to get rid of the pest. Even after a year of fallowing and intensive cultivation, there were, in February 1948, nearly 4½ million growing wild oat plants per acre in spite of continued scuffling and harrowing, there were again 3½ million plants in April, and 2½ million in June. Hardly any further wild oats germinated for the rest of the year, but in March 1949, after nearly 2½ years of fallow, 32,000 living wild oat plants per acre were again found. It is clear that once an area becomes infested with this pest, it needs a period of over two years of intensive cultivation before the area can be cleared.

There was a very serious extension of the attacks of fleabeetle on certain crops in 1948. Up till recently this pest was considered as a specific enemy of Brassica crops, and a real danger only in a dry season. In the last year or two, however, and particularly in 1948, it has done serious damage not only to Brassica but also to lucerne and to linseed. In spite of measures against it with D.D.T. and other insecticides, one experimental crop of lucerne was lost in 1948 and had to be resown, and the effect on late planted linseed was very serious. In this matter other people in the Woburn neighbourhood suffered equally with ourselves.

One of the matters which have for a number of years been a feature of the Woburn station has been the growing of certain exotic crops which seem to have possibilities in this country especially on the well drained, but semi-acid, soil which is characteristic of the station. The crops of this kind grown in 1948 have been hybrid maize from the United States, sweet lupins for forage, soya beans, and the well known continental forage crop, serradella. The weather of 1948 was not at all suitable for these crops, all of which usually grow in conditions where the summer is very much warmer than is the case in England, for the year under report had a cold, wet summer, and also a wet autumn at the time when most of these crops normally ripen. With regard to maize, however,

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where we grew several of the early Wisconsin hybrids (seed of which was kindly supplied by Dr. Neal of that State), it was possible to ripen several of the types supplied, though they required from 170 to 180 days from the date of sowing as against 80 days or thereabouts in America. The yield obtained was much greater than it has been possible to obtain from other early types, and the best yielded 27·5 cwt. of dry grain per acre, a yield which makes the growing of such hybrids for grain quite a possibility in this country. The ordinary hybrid types grown in the U.S.A. proved themselves far too late in a summer like that of 1948 to be of any use for grain production, though they furnished excellent cobs for use as a vegetable and would be a most valuable silage crop.

Another crop which we have been testing for several years is sweet lupins considered as a forage crop. This was evolved originally in Germany, but it has been further developed by Mr. Oldershaw of Ipswich. The special virtue of sweet lupins as a forage crop is that they grow on very sandy land which is distinctly acid—conditions which are not favourable to most forage crops. All the types grown in 1948, except the blue variety, grew well on the Woburn semi-acid land and gave very large yields of fodder, being as great as 30 to 40 tons of green material per acre after two to three months of growth. The fodder was eaten by cattle though not with much relish, and it seems that in these varieties we have a source of forage on land which will not produce the more normal kinds. The blue types of lupin were a failure, being almost entirely wiped out by a wilt (*Fusarium avenaceum*), which was identified at the Government Plant Pathology Laboratory.

As regards soya beans, we have again grown the early dwarf type, Manitoba Brown, which ripened normally but yields so poorly that it cannot be the basis of an industry. The more normal types grown commonly in the United States will not ripen in this country, especially in a cold, wet summer as in 1948, and, in fact, a small area of the 'Lincoln' variety never even formed pods, though it grew well up to the point of flowering.

We have also made preliminary experiments with serradella as a fodder crop, suited for such land as that at Woburn, and though it grew well the yield of fodder was very small compared with what I have seen in warmer regions on soil otherwise not very dissimilar. This will be again tested under summer conditions with, it is hoped, a more normal temperature.

Pot Experiments

Clover Sickness

The study of this obscure affection of clover has continued and we can record distinct progress in elucidating the nature of the disease. It is now clear that the speed of onset of the affection depends on the actual amount of clover which has grown in the soil, and by increasing the proportion of clover to soil the rapidity with which the soil becomes sick can be greatly increased. Further the partial sterilization of the soil by toluene or even by formalin does little to get rid of the disease in a badly affected soil, and even the oxidation of the more reactive organic materials in the soil has little effect.

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Competition of crop plants with certain weeds

After a series of years in which we have studied the competition of barley and certain weeds, including two types of twitch and three of the commoner annual weeds, we have in 1948 widened the scope of the investigation to include the effect of clover as a competitor with barley when they are grown together. The results which are now being worked up promise to be of considerable interest in view of the fat that clover is so commonly grown with barley in ordinary farm practice.

The nutrition of crops under very acid soil conditions

For a number of years an investigation has been in progress 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. The particular phase of the study in 1948 has been to ascertain how far the addition of calcium can be effective when given in such a form that the acidity of the soil was not or little affected, any soluble aluminium being at the same time precipitated. In no case was the addition, even of a fairly large quantity of such calcium, effective, unless the acidity of the soil was also reduced. The relative parts which acidity as such, the presence of soluble aluminium, and the absence of calcium in an assimilable form take in preventing the growth of barley on an acid soil have been the subject of an enormous amount of research, particularly in America, but the matter is still not completely elucidated, and the present investigations are taking advantage of some extremely acid soils at Woburn to make further efforts to clear up the question.

LABORATORY WORK

The main work of the laboratory at Woburn is to enable us to follow the behaviour of the crops which are being grown in the field experiments and the changes in the soil on which they are grown. This requires the attention of almost the whole time of Mr. Barnes and the laboratory staff. But we have this year continued the examination of the very large number of soil samples which have been obtained from the field at various stages of the long term experiments. The main study at present is that of the sulphur in various forms in the soils from the permanent barley experiments. I had hoped to give a fuller account of the results so far obtained in this study, but this must, I think, wait for the further work being done in 1949.

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